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MEMORANDUM REPORT NO. 1330
MARCH 1961

DOPLOC OBSERVATIONS OF

REFLECTION CROSS SECTIONS OF SATELLITES

ARPA Satellite Fence Series

Harold T. Lootens

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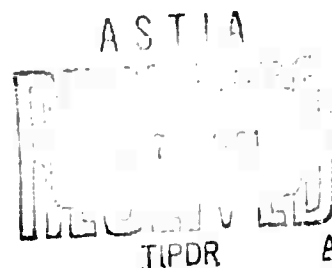
BALLISTIC RESEARCH LABORATORIES

ABERDEEN PROVING GROUND, MARYLAND

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Ballistic Measurements Laboratory

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HTLootens/bt
Aberdeen Proving Ground, Maryland
March 1961

DOPLOC OBSERVATIONS OF REFLECTION CROSS SECTIONS OF SATELLITES

ABSTRACT

This report presents reflection cross sections observed for eight satellites during the period 1 January 1959 to 1 July 1960, using the DOPLOC "dark satellite" detection system developed by the Ballistic Research Laboratories. Several related areas are discussed; i.e., satellite "signature", spin and tumble, scintillation and ionized trails. A brief description of the DOPLOC receiving system and antenna configuration is included. The method used for calculation of cross sections is given in Appendix I.

TABLE OF CONTENTS

LIST OF FIGURES

29. ARPA-BRL DOPLOC Doppler Record of 58 Delta, Rev. 9612

30. ARPA-BRL DOPLOC Doppler Record of 58 Delta, Rev. 9716

31. ARPA-BRL DOPLOC Doppler Record of 58 Delta, Rev. 9722

32. ARPA-BRL DOPLOC Doppler Record of 58 Delta, Rev. 9826

33. ARPA-BRL DOPLOC Doppler Record of 58 Delta, Rev. 9832

34. ARPA-BRL DOPLOC Doppler Record of 58 Delta, Rev. 9842

35. ARPA-BRL DOPLOC Doppler Record of 58 Delta, Rev. 9848

36. ARPA-BRL DOPLOC Doppler Record of 58 Delta, Rev. 9905

37. ARPA-BRL DOPLOC Doppler Record of 58 Delta, Rev. 9927

38. ARPA-BRL DOPLOC Doppler Record of 58 Delta, Rev. 9937

39. ARPA-BRL DOPLOC Doppler Record of 58 Delta, Rev. 9943

40. ARPA-BRL DOPLOC Doppler Record of 58 Delta, Rev. 9959

41. ARPA-BRL DOPLOC Doppler Record of 58 Delta, Rev. 9975

42. ARPA-BRL DOPLOC Doppler Record of 58 Delta, Rev. 9991

43. ARPA-BRL DOPLOC Doppler Record of 58 Delta, Rev. 10001

44. ARPA-BRL DOPLOC Doppler Record of 58 Delta, Rev. 10007

45. ARPA-BRL DOPLOC Doppler Record of 58 Delta, Rev. 10023

46. ARPA-BRL DOPLOC Doppler Record of 59 Epsilon, Rev. 53

47. ARPA-BRL DOPLOC Doppler Record of 59 Epsilon, Rev. 60

48. ARPA-BRL DOPLOC Doppler Record of 59 Epsilon, Rev. 121

49. ARPA-BRL DOPLOC Doppler Record of 59 Epsilon, Rev. 314

50. ARPA-BRL DOPLOC Doppler Record of 59 Epsilon, Rev. 414

51. ARPA-BRL DOPLOC Doppler Record of 59 Epsilon, Rev. 438

52. ARPA-BRL DOPLOC Doppler Record of 59 Epsilon, Rev. 532

53. ARPA-BRL DOPLOC Doppler Record of 59 Zeta, Rev. 14

54. ARPA-BRL DOPLOC Doppler Record of 59 Zeta, Rev. 150

55. ARPA-BRL DOPLOC Doppler Record of 59 Zeta, Rev. 241

56. ARPA-BRL DOPLOC Doppler Record of 59 Zeta, Rev. 556

57. ARPA-BRL DOPLOC Doppler Record of 59 Zeta, Rev. 855

58. ARPA-BRL DOPLOC Doppler Record of 59 Zeta, Rev. 871

59. ARPA-BRL DOPLOC Doppler Record of 59 Zeta, Rev. 887

60. ARPA-BRL DOPLOC Doppler Record of 59 Kappa, Rev. 183

61. ARPA-BRL DOPLOC Doppler Record of 59 Lambda, Rev. 96

62. ARPA-BRL DOPLOC Doppler Record of 59 Lambda, Rev. 138

63. ARPA-BRL DOPLOC Doppler Record of 59 Lambda, Rev. 278

64. ARPA-BRL DOPLOC Doppler Record of 59 Lambda, Rev. 685

65. ARPA-BRL DOPLOC Doppler Record of 59 Lambda, Rev. 1285

66. ARPA-BRL DOPLOC Doppler Record of 59 Lambda, Rev. 1516

67. ARPA-BRL DOPLOC Doppler Record of 60 Gamma 1, Rev. 318

68. ARPA-BRL DOPLOC Doppler Record of 60 Gamma 1, Rev. 403

69. ARPA-BRL DOPLOC Doppler Record of 60 Gamma 1, Rev. 418

70. ARPA-BRL DOPLOC Doppler Record of 60 Gamma 1, Rev. 836

71. ARPA-BRL DOPLOC Doppler Record of 60 Gamma 1, Rev. 960

72. ARPA-BRL DOPLOC Doppler Record of 60 Gamma 2, Rev. 1042

73. ARPA-BRL DOPLOC Doppler Record of 60 Delta, Rev. 30

74. ARPA-BRL DOPLOC Doppler Record of 60 Delta, Rev. 61

75. ARPA-BRL DOPLOC Doppler Record of 60 Delta, Rev. 117

76. ARPA-BRL DOPLOC Doppler Record of 60 Delta, Rev. 124

77. ARPA-BRL DOPLOC Doppler Record of 60 Delta, Rev. 140

78. ARPA-BRL DOPLOC Doppler Record of 60 Delta, Rev. 156

79. ARPA-BRL DOPLOC Doppler Record of 60 Delta, Rev. 165

80. ARPA-BRL DOPLOC Doppler Record of 60 Delta, Rev. 172

81. ARPA-BRL DOPLOC Doppler Record of 60 Epsilon 1, Rev. 53

82. ARPA-BRL DOPLOC Doppler Record of 60 Epsilon 1, Rev. 99

83. ARPA-BRL DOPLOC Doppler Record of 60 Epsilon 1, Rev. 150

84. ARPA-BRL DOPLOC Doppler Record of 60 Epsilon 1, Rev. 165

85. ARPA-BRL DOPLOC Doppler Record of 60 Epsilon 1, Rev. 386

86. ARPA-BRL DOPLOC Doppler Record of 60 Epsilon 1, Rev. 522

87. ARPA-BRL DOPLOC Doppler Record of 60 Epsilon 2, Rev. 106

88. ARPA-BRL DOPLOC Doppler Record of 60 Epsilon 2, Rev. 137

89. ARPA-BRL DOPLOC Doppler Record of 60 Epsilon 2, Rev. 147

90. ARPA-BRL DOPLOC Doppler Record of 60 Epsilon 2, Rev. 153

91. ARPA-BRL DOPLOC Doppler Record of 60 Epsilon 2, Rev. 194

92. ARPA-BRL DOPLOC Doppler Record of 60 Epsilon 2, Rev. 303

93. ARPA-BRL DOPLOC Doppler Record of 60 Epsilon 2, Rev. 309

94. ARPA-BRL DOPLOC Doppler Record of 60 Epsilon 2, Rev. 356

9

I. INTRODUCTION

During the period 1 January 1959 to 1 July 1960, the Ballistic
Research Laboratories, under funding from the Advanced Research Projects
Agency (ARPA Order 8-58), operated a three-station, reflection Doppler
satellite tracking system, extending across the south-central United
States from Tennessee to New Mexico. This system, known as DOPLOC
(DOppler Phase LOCk), provided a means of detecting and tracking radio-
silent, or "dark" satellites.

A transmitting station was located at Fort Sill, Oklahoma and
receiving stations were located at White Sands Missile Range, New Mexico
and at Forrest City, Arkansas. The stations were initially manned on a
twenty-four hour, seven-day-per-week basis, as part of the nation-wide
satellite surveillance net. Following permission from ARPA to discontinue
routine twenty-four hour operation, the White Sands station was deactivated
and a basic eight-hour work day was adopted at the Fort Sill and Forrest
City stations on or about 1 October 1959. The actual hours of operation
were chosen to adapt the work schedule to the times of most frequent
satellite passes.

The flexible schedule by which the field stations operated has
provided considerable data from known satellites, Unidentified Flying
Objects (UFO's) and meteors. Many satellites and UFO's have been
successfully detected and tracked by the DOPLOC technique and their time
of crossing, altitude, east-west position and effective reflection cross
section determined from single pass data from a single receiving station.
Crossing time and position data was forwarded to Space Track Control
Center for inclusion in their orbital prediction program.

11

II. DOPLOC SYSTEM DESCRIPTION

A. Equipment

The DOPLOC system consisted of a 50-kw continuous wave, 108 Mc/s transmitter located at Fort Sill, Oklahoma, which fed one of three narrow-beam, high-gain antennas. These high-gain antennas emitted narrow, fan-shaped beams, one directed 20 degrees above the northern horizon, one directed vertically and one directed 20 degrees above the southern horizon (see Figure 1).

The signal reflected from a satellite passing through the transmitter beam was received at one or both of the receiving stations. Each receiving station had three high-gain antennas oriented to "see" the space volume illuminated by the transmitter. The reflected Doppler signal was fed through a receiver to a bank of fixed audio frequency filters known as the Automatic Lock-On (ALO) and, subsequently, to a narrow band, phase-locked tracking filter. The appearance of a Doppler signal in one of the fixed filters activated a control circuit which pulled the tracking filter frequency over to the signal frequency and caused a phase lock between the two. The tracking filter then tracked the Doppler signal frequency continuously as the satellite passed through the antenna beam. Block diagrams of the DOPLOC receiving system and ALO are shown in Figures 2, 3, 4 and 5.

A satellite which crossed the base line joining the transmitter and receiver traversed each of the three overlapping, fan-shaped antenna beams (see Figure 6). This resulted in three separate Doppler records, one for each of the three antennas, separated in time by 30 - 60 seconds. The length of the records varied, averaging about 7 seconds in the center antenna and 15 - 25 seconds in the north and south antennas. The digital Doppler data as a function of time were printed on paper tape and also converted to binary form and punched into standard five-hole teletype tape for transmission via commercial teletype to the BRL computer center, where they were fed to the ORDVAC computer to obtain satellite orbital

12

parameters. Figure 7 shows typical DOPLOC data output and Figure 8 shows a typical orbital solution calculated using this type of data. In addition to recording the digital data, recordings on paper charts were made of the Doppler analog frequency and signal strength with respect to time. Reproductions of these records are presented in this report.

B. Antenna Dimensions and Orientation

The special high-gain antennas were 60 feet long and 10 feet wide with beam dimensions of 8 x 76 degrees and a gain of 16 db over isotropic. Three of these antennas were installed at each of the receiving stations and at the transmitting station. The antenna installation at the transmitting station is shown in Figure 9.

When the DOPLOC satellite detection system assumed twenty-four hour operational status in January 1959, the transmitter at Fort Sill served as the illuminator for both receiving stations. At that time, the high-gain antennas were oriented in azimuth and elevation as shown in Figure 10. In the fall of 1959, the receiving station at White Sands was de-activated and it was decided to tilt the antennas at Fort Sill and Forrest City to produce more favorable coverage. The reorientation of the antennas to the configuration shown in Figure 11 was made in November 1959.

A complete and detailed description of the DOPLOC satellite detection and tracking system may be found in BRL Report No. 1123, "The DOPLOC Instrumentation System for Satellite Tracking" (February 1961).

13

III. FIELD DATA

A. Satellite Records

During the 18-month operation of the DOPLOC system, 111 reflections were received, resulting from observations of 89 individual satellite passes. More than half of these reflections were received by the center antenna alone, while the rest were observed by the north or south antennas or various combinations of the three antennas.

Reproductions of DOPLOC Doppler reflection data are presented as follows:

Sputnik III (58 Delta), Figures 12 to 45; Discoverer V (59 Epsilon), Figures 46 to 52; Discoverer VI (59 Zeta), Figures 53 to 59; Discoverer VII (59 Kappa), Figure 60; Discoverer VIII (59 Lambda), Figures 61 to 66; Transit 1B rocket (60 Gamma 1), Figures 67 to 71; Transit 1B (60 Gamma 2), Figure 72; Discoverer XI (60 Delta), Figures 73 to 80; Sputnik IV (60 Epsilon 1), Figures 81 to 86; Sputnik IV rocket (60 Epsilon 2), Figures 87 to 95; Sputnik IV fragments (60 Epsilon 3, 4, 5 and 6), Figures 96 to 100. A summary of these reflections arranged by satellite and antenna is given in Table 1, and a detailed explanation of each pass may be found in Table 2.

B. Unidentified Flying Objects

A number of reflections were received and recorded which could not be correlated with the predicted position of any known satellite. These were termed Unidentified Flying Objects and reproductions of 14 of these reflections are shown in Figures 101 to 114, with a detailed listing in Table 3.

14

TABLE I

DOPLOC SATELLITE REFLECTION SUMMARY
1 January 1959 - 1 July 1960

Satellite Name	Designation	Center	North	South	North & Center	South & Center	North & South	Three Antenna	Total
Sputnik III	58 Delta	19	8	2	1	3	-	1	34
Discoverer V	59 Epsilon	5	-	2	-	-	-	-	7
Discoverer VI	59 Zeta	6	-	1	-	-	-	-	7
Discoverer VII	59 Kappa	1	-	-	-	-	-	-	1
Discoverer VIII	59 Lambda	4	-	-	1	1	-	-	6
Transit 1B (rocket)	60 Gamma 1	5	-	-	-	-	-	-	5
Transit 1B	60 Gamma 2	1	-	-	-	-	-	-	1
Discoverer VI	60 Delta	-	-	1	-	-	1	6	8
Sputnik IV	60 Epsilon 1	3	1	2	1	-	-	-	6
Sputnik IV (rocket)	60 Epsilon 2	4	2	2	1	-	-	-	9
Sputnik IV (fragment)	60 Epsilon 3	1	-	-	-	-	-	-	1
Sputnik IV (fragment)	60 Epsilon 4	1	-	-	-	-	-	-	1
Sputnik IV (fragment)	60 Epsilon 5	1	-	-	-	-	-	-	1
Sputnik IV (fragment	60 Epsilon 6	2	-	-	-	-	-	-	2
	Totals	53	11	10	3	4	1	7	89
Unidentified Objects		16	-	-	-	-	-	-	16

15

TABLE 2

DOPLOC SATELLITE REFLECTIONS, 1 JANUARY 1959 - 1 JULY 1960

Satellite Name	Rev Number	Date 1959 - 60	Time G.M.T.	Pass Direction	Altitude Miles	GR(1) Miles	Signal Duration Seconds	Slope cps/s	Peak Signal dbw	Remarks
58 Delta	6844	11 Sep 59	0140:12	N-S	407	283 E	9	47	- 171.0	HERUN
58 Delta	7049	24 Sep 59	2201:56	N-S	575	214 E	10	21	- 172.0	
58 Delta	7358	15 Oct 59	1646:25	N-S	569	74 W	3	60	- 176.5	
58 Delta	8386	22 Dec 59	2136:23	N-S	172	176 E	7	81	- 166.5	
58 Delta	8643	8 Jan 60	1647:25	N-S	158	129 E	7	86	- 170.0	
58 Delta	8685	11 Jan 60	0651:30	S-N	413	Overhead	4	48	- 175.0	
58 Delta	8719	13 Jan 60	1530:03	N-S	186	50 E	4	94	- 171.0	
58 Delta	8734	14 Jan 60	1454:02	N-S	186	226 E	5	84	- 170.0	
58 Delta	8795	18 Jan 60	1358:01	N-S	146	158 E	6	84	- 172.4	
58 Delta	9009	1 Feb 60	1011:12	N-S	154	46 W	4	118	- 172.0	
58 Delta	9172	11 Feb 60	2121:06	S-N	315	230 E	9	52	- 178.0	
58 Delta	9255	17 Feb 60	0523:57	N-S	128	120 E	11	91	- 161.0	
58 Delta	9286	19 Feb 60	0458:45	N-S	123	33 W	5	106	- 166.5	
58 Delta	9466	1 Mar 60	1552:58	S-N	275	289 E	15	58	- 167.5	
58 Delta	9472	2 Mar 60	0127:31	N-S	130	80 W	4	94	- 172.0	
58 Delta	9505	4 Mar 60	0041:30	N-S	130	56 E	7	90	- 170.0	
58 Delta	9581	8 Mar 60	2317:41	N-S	146	33 E	8	104	- 168.0	
58 Delta	9612	10 Mar 60	2218:33	N-S	116	199 E	25	25	- 171.0	North Antenna
58 Delta	9716	17 Mar 60	1114:54	S-N	275	135 E	4	70	- 175.0	South Antenna
58 Delta	9722	17 Mar 60	2044:31	N-S	113	4 E	17	27	- 178.0	
58 Delta	9826	24 Mar 60	0847:25	S-N	182	405 E	5	83	- 175.5	
58 Delta (2)	9852	24 Mar 60	1812:26	N-S	100	280 E	6	113	- 170.5	
58 Delta (2)	9852	24 Mar 60	1813:19	N-S	100	292 E	24	18	- 175.0	South Antenna
58 Delta (2)	9842	25 Mar 60	0848:40	S-N	182	381 E	25	16	- 177.0	North Antenna
58 Delta (2)	9848	25 Mar 60	1811:46	N-S	100	155 E	5	104	- 171.5	South Antenna
58 Delta (2)	9848	25 Mar 60	1812:38	N-S	100	266 E	16	36	- 173.0	South Antenna

16

TABLE 2 (continued)

Satellite Name	Rev Number	Date 1959 - 60	Time G.M.T.	Pass Direction	Altitude Miles	GR(1) Miles	Signal Duration Seconds	Slope cps/s	Peak Signal dbm	Remarks
58 Delta	9905	29 Mar 60	0659:58	S-N	172	240 E	17	22	- 178.0	South Antenna
58 Delta	9927	30 Mar 60	1613:25	N-S	105	258 E	22	57	- 166.0	North Antenna
58 Delta (3)	9937	31 Mar 60	0641:14	S-N	180	102 E	26	22	- 172.0	South Antenna
58 Delta (3)	9937	31 Mar 60	0642:57	S-N	180	172 E	7	89	- 162.0	South Antenna
58 Delta (5)	9957	31 Mar 60	0644:19	S-N	180	470 E	12	11	- 178.0	North Antenna
58 Delta (4)	9943	31 Mar 60	1601:53	N-S	104	294 E	46	57	- 145.0	North Antenna
58 Delta (4)	9943	31 Mar 60	1603:20	N-S	104	420 E	7	127	- 166.0	North Antenna
58 Delta	9959	1 Apr 60	1547:58	N-S	103	102 E	57	28	- 166.0	North Antenna
58 Delta	9975	2 Apr 60	1530:24	N-S	104	90 E	5	28	- 177.5	North Antenna
58 Delta	9991	3 Apr 60	1409:18	N-S	97	140 E	22	21	- 170.5	North Antenna
58 Delta (2)	10001	4 Apr 60	0629:11	S-N	124	206 E	40	26	- 177.5	South Antenna
58 Delta (2)	10001	4 Apr 60	0530:49	S-N	124	284 E	5	91	- 162.4	South Antenna
58 Delta	10007	4 Apr 60	1444:27	N-S	97	277 E	22	26	- 166.5	North Antenna
58 Delta	10023	5 Apr 60	1415:05	N-S	97	145 E	5	40	- 179.0	North Antenna
59 Epsilon	53	17 Aug 59	0539:54	S-N	341	209 E	7	57	- 177.0	
59 Epsilon	60	17 Aug 59	1704:10	N-S	240	76 E	8	108	- 177.0	
59 Epsilon	121	21 Aug 59	1620:02	N-S	140	100 E	20	20	- 171.0	South Antenna
59 Epsilon	314	3 Sep 59	0309:50	S-N	185	191 E	7	89	- 168.0	South Antenna
59 Epsilon	414	9 Sep 59	1322:15	N-S	211	17 E	6	88	- 169.0	
59 Epsilon	438	11 Sep 59	0141:16	S-N	190	413 E	9	108	- 163.5	RERUN
59 Epsilon	532	17 Sep 59	0105:49	S-N	132	32 E	30	18	- 167.5	South Antenna - RERUN
59 Zeta	14	20 Aug 59	1741:51	N-S	146	145 E	6	119	- 167.0	
59 Zeta	150	29 Aug 59	1650:08	N-S	172	15 E	22	15	- 174.5	South Antenna
59 Zeta	241	4 Sep 59	1559:34	N-S	213	123 E	7	86	- 163.5	RERUN
59 Zeta	556	25 Sep 59	0144:16	S-N	129	265 E	4	126	- 178.0	
59 Zeta	855	13 Oct 59	2347:38	S-N	138	179 E	7	92	- 169.0	
59 Zeta	871	14 Oct 59	2342:09	S-N	175	108 E	9	91	- 168.0	
59 Zeta	887	15 Oct 59	2332:58	S-N	170	123 E	7	93	- 164.5	

17

TABLE 2 (continued)

Satellite Name	Rev Number	Date 1959 - 60	Time G.M.T.	Pass Direction	Altitude Miles	GR(?) Miles	Signal Duration Seconds	Slope cps/s	Peak Signal dbw	Remarks
59 Kappa	183	19 Nov 59	1704:59	N-S	115	414 E	5	134	- 161.0	
59 Lambda	96	27 Nov 59	1647:25	N-S	124	429 E	23	110	- 164.0	
59 Lambda	138	30 Nov 59	1644:41	N-S	138	Overhead	5	127	- 168.0	
59 Lambda (4)	278	10 Dec 59	1503:57	N-S	218	8 E	10	32	- 170.5	North Antenna - RERUN
59 Lambda (4)	278	10 Dec 59	1505:02	N-S	218	95 E	4	85	- 164.5	
59 Lambda (2)	685	8 Jan 60	0016:01	S-N	138	60 N	10	26	- 175.5	South Antenna
59 Lambda (2)	685	8 Jan 60	0017:05	S-N	138	26 N	4	26	- 172.5	RERUN
59 Lambda	1285	17 Feb 60	0513:53	N-S	156	542 E	11	142	- 168.5	
59 Lambda	1516	3 Mar 60	0256:10	N-S	157	269 E	11	99	- 166.0	
60 Gamma 1	318	4 May 60	1257:23	N-S	440	187 E	4	85	- 174.0	
60 Gamma 1	403	10 May 60	0517:28	S-N	271	400 E	4	53	- 171.0	
60 Gamma 1	418	11 May 60	0303:26	S-N	287	212 E	13	45	- 171.0	
60 Gamma 1	836	7 Jun 60	1632:12	S-N	512	225 E	15	51	- 167.0	
60 Gamma 1	960	15 Jun 60	2048:10	N-S	204	154 E	22	66	- 165.0	
60 Gamma 2	1042	21 Jun 60	1902:09	N-S	250	233 E	22	95	- 171.0	
60 Delta (3)	30	17 Apr 60	1838:12	N-S	111	43 E	12	26	- 174.0	North Antenna
60 Delta (3)	30	17 Apr 60	1839:19	N-S	111	72 E	5	127	- 168.0	
60 Delta (3)	61	19 Apr 60	1840:06	N-S	111	110 E	7	53	- 176.0	South Antenna
60 Delta (5)	61	19 Apr 60	1801:53	N-S	111	230 E	21	55	- 174.0	North Antenna
60 Delta (5)	117	23 Apr 60	1803:50	S-N	204	526 E	6	19	- 169.0	South Antenna
60 Delta	124	23 Apr 60	0627:41	N-S	120	185 E	17	11	- 174.0	South Antenna
60 Delta (5)	124	23 Apr 60	1727:08	N-S	120	250 E	42	34	- 164.0	North Antenna
60 Delta (3)	124	23 Apr 60	1728:18	N-S	120	420 E	6	118	- 167.0	
60 Delta (5)	140	24 Apr 60	1729:25	N-S	116	360 E	5	21	- 176.0	South Antenna
60 Delta (3)	140	24 Apr 60	1727:00	N-S	116	281 E	21	21	- 161.0	North Antenna
60 Delta (3)	140	24 Apr 60	1728:57	N-S	116	259 E	24	29	- 169.0	South Antenna

TABLE 2 (continued)

Satellite Name	Rev Number	Date 1959 - 60	Time G.M.T.	Pass Direction	Altitude Miles	GR[1] Miles	Signal Duration Seconds	Slope cps/s	Peak Signal dbw	Remarks
60 Delta (3)	156	25 Apr 60	1717:39	N-S	112	107 M	11	29	- 167.0	North Antenna
60 Delta (3)	156	25 Apr 60	1718:40	N-S	112	143 M	9	119	- 175.0	
60 Delta (3)	156	25 Apr 60	1719:31	N-S	112	181 M	5	40	- 175.0	South Antenna
60 Delta (3)	165	26 Apr 60	0509:55	S-N	142	64 M	4	11	- 172.0	South Antenna
60 Delta (3)	165	26 Apr 60	0611:13	S-N	142	99 M	8	112	- 165.0	
60 Delta (3)	165	26 Apr 60	0612:06	S-N	142	189 M	34	27	- 165.0	North Antenna
60 Delta (3)(6)	172	26 Apr 60	1653:09	N-S	77	255 M	19	42	- 170.0	North Antenna
60 Delta (3)(6)	172	26 Apr 60	1653:56	N-S	77	770 M	4	162	- 160.0	
60 Delta (3)(6)	172	26 Apr 60	1654:29	N-S	77	485 M	9	40	- 168.0	South Antenna
60 Epsilon 1	53	18 May 60	0833:05	S-N	124	252 M	30	35	- 168.0	South Antenna
60 Epsilon 1	99	21 May 60	0821:32	S-N	200	405 M	40	19	- 172.0	North Antenna
60 Epsilon 1	150	24 May 60	1653:44	N-S	287	291 M	20	10	- 177.0	South Antenna
60 Epsilon 1	165	25 May 60	1624:59	N-S	288	96 M	11	68	- 161.5	
60 Epsilon 1	386	9 Jun 60	0300:41	S-N	230	39 M	10	76	- 169.0	
60 Epsilon 1	522	18 Jun 60	0028:41	S-N	225	50 M	8	77	- 165.0	
60 Epsilon 2	106	21 May 60	1733:24	N-S	208	263 M	14	34	- 176.0	South Antenna
60 Epsilon 2	157	23 May 60	1635:46	N-S	209	274 M	5	78	- 171.5	
60 Epsilon 2 (4)	147	24 May 60	0720:57	S-N	240	90 M	8	81	- 174.5	
60 Epsilon 2 (4)	147	24 May 60	0722:37	S-N	240	451 M	42	16	- 172.5	North Antenna
60 Epsilon 2	153	24 May 60	1655:14	N-S	209	112 M	14	16	- 178.5	South Antenna
60 Epsilon 2	194	27 May 60	0642:00	S-N	193	159 M	45	22	- 174.5	North Antenna
60 Epsilon 2	303	3 Jun 60	0354:58	S-N	215	420 M	7	81	- 176.5	
60 Epsilon 2	309	5 Jun 60	1325:57	N-S	205	305 M	7	74	- 165.0	
60 Epsilon 2	356	6 Jun 60	1240:39	N-S	201	30 M	15	23	- 172.0	North Antenna
60 Epsilon 2	617	22 Jun 60	2218:14	S-N	203	77 M	11	81	- 177.0	
60 Epsilon 3	280	2 Jun 60	0441:29	S-N	232	358 M	12	74	- 166.0	

19

TABLE 2 (continued)

Satellite Name	Rev Number	Date 1959 - 60	Time G.M.T.	Pass Direction	Altitude Miles	$GR^{(1)}$ Miles	Signal Duration Seconds	Slope cps/s	Peak Signal dbw	Remarks
60 Epsilon 4	280	2 Jun 60	0444:21	S-N	240	270 E	11	69	-177.0	
60 Epsilon 5	569	20 Jun 60	2325:46	S-N	205	231 E	12	65	-166.0	
60 Epsilon 6	265	1 Jun 60	0502:06	S-N	219	210 E	14	67	-162.0	
60 Epsilon 6	301	3 Jun 60	1359:22	N-S	234	169 E		70	-174.0	

General Notes:

1. Transmitting antenna tilted toward receiving antenna 26 October 1959.
2. ALO scan changed to 4 kc 27 November 1959.
3. All passes acquired by center antenna unless otherwise noted.
4. Under remarks, "RERUN" indicates original signal not acquired by ALO. Pass was recovered from playback of magnetic tape.
5. Slope denotes rate of change of Doppler frequency.

References:

(1) Ground range East, West or Overhead Fort Sill transmitter.
(2) Acquired by South and Center antennas.
(3) Acquired by North, Center and South antennas.
(4) Acquired by North and Center antennas.
(5) Acquired by North and South antennas.
(6) Terminal revolution.

TABLE 2

DOPLOC UNIDENTIFIED OBJECT REFLECTIONS

1 January 1959 - 1 July 1960

DATE 1959-60	TIME G.M.T.	ALTITUDE MILES	G. R. (1) MILES	SIGNAL DURATION SECONDS	SLOPE(2) cps/s	PEAK SIGNAL dbw	REMARKS
17 Aug 59	1703:30	125	Overhead	7.0	110	-166.0	59 Epsilon 2 (3)
14 Sep 59	1514:01	432	318 E	2.0	50	-171.5	
22 Sep 59	1643:04	398	140 E	5.0	50	-159.0	
1 Oct 59	0235:22	190	117 E	5.0	100	-164.0	
15 Oct 59	1641:31	178	115 E	4.0	113	-184.0	59 Epsilon 2 (3)
11 Dec 59	2258:01	100	20 W	5.0	142	-164.5	
16 Dec 59	1843:18	198	165 E	3.0	83	-161.0	
14 Jan 60	2056:00	485	140 E	6.0	46	-170.0	59 Epsilon 2 (3)
11 Feb 60	2119:13	900	Overhead	8.0	20	-179.0	
12 Feb 60	2146:10	190	135 E	3.5	93	-177.0	
18 Feb 60	0101:22	265	40 E	5.0	70	-159.0	
1 Mar 60	0057:04	190	130 E	4.0	91	-167.5	
1 Mar 60	0120:43	195	117 E	3.5	85	-159.0	
29 Mar 60	0906:33	300	90 W	2.5	61	-174.0	

All reflections received on center antenna.

NOTES: (1) Ground range East, West or Overhead Fort Sill transmitter.

(2) Rate of change of Doppler frequency.

(3) Tentatively identified as the recovery capsule from Discoverer V (59 Epsilon 1).

C. Doppler Recording

The typical form in which DOPLOC data are recorded for satellite detection is shown in Figure 60, a record of Discoverer VII (59 Kappa). An explanation of this record and the ALO device by which it was obtained follows. The upper portion of the chart is an analog record of tracking filter output frequency. The short, evenly spaced marks indicate the successive frequencies at which the tracking filter is set while the system is in the search mode. The tracking filter is stepped in 1 kc/s intervals to maintain a frequency midway in the 1 kc/s spectrum to which the comb filters are set. This minimizes the time required to pull the tracking filter frequency to a signal frequency detected in one of the fixed filters. The comb filter bank consists of ten filters, each with a 20 c/s bandwidth, spaced 100 c/s apart. The filter bank "looks" at a 1 kc/s frequency band for 0.1 second; then it is switched up 1 kc/s by a heterodyne method and this process continues, until either the desired frequency band has been covered or a signal is detected. Figure 60 shows the tracking filter output when a 12 kc/s scan is used. The ALO can also be adjusted to scan a 4 kc/s range (see Figure 19) or a 2 kc/s range (see Figure 24), or it may be manually positioned to a desired frequency value. Manual operation is useful when attempting to lock the filter on a signal being played back from magnetic tape, where the initial Doppler frequency is known within a few cycles per second. Figures 13 and 22 are examples of manual filter positioning.

The initiation of phase-locked tracking is accomplished quickly when a signal frequency is detected in one of the fixed filters. The control circuit pulls the tracking filter frequency over to the received Doppler signal frequency in about 10 milliseconds and within 80 to 90 milliseconds all transients have subsided and phase-locked tracking begins. Figure 60 shows this transition from step scanning to continuous tracking at 1714:58 Z time. Concurrently, the digital counter and printer is started and the time period of 1000 cycles of the Doppler is printed at one second intervals on paper tape. Simultaneously, the period count is converted to binary form

22

and punched into five-hole teletype tape. The Doppler period count for Revolution 183 of 59 Kappa, which corresponds to the Doppler frequency analog record, is shown at the top left of Figure 60. The right five digits constitute the count, while the left six digits represent Universal Time in hours, minutes and seconds. The Doppler frequency in cycles per second is 10^8 times the reciprocal of the count. A Doppler frequency record readable to 0.1 c/s is obtained in this manner. If desired, the Doppler frequency may also be printed directly in digital form (see Figure 7).

D. Signal Strength

The lower part of the chart in Figure 60 is a record of the AGC voltage from the tracking filter. While in the search mode, the AGC is shorted, giving the clean, straight line at 2 mm deflection. When a signal is detected, the AGC voltage first decreases due to an initial threshold voltage of opposite polarity existing on the AGC line, which causes a deflection toward zero on the chart. Then, as the signal amplitude increases, the AGC voltage increases as shown by the scale calibration. The chart is calibrated in power input level (in dbw) to the receiver input terminals and also in relative signal in terms of the signal-to-noise ratio at the receiver output, i.e., in db below 1:1 S/N at the receiver output. With a 10 c/s bandwidth, the tracking filter can track signals that are 26 db down in the noise from the 16 kc/s bandwidth receiver.

The signal strength record of 59 Kappa in Figure 60 shows a maximum signal of -161 dbw which is 2 db down in the noise at the receiver output. The rather narrow, peaked signal response curve with the slight dip on the leading portion is "signature" information indicating considerable attitude change during the six second passage time through the antenna beam. The peak cross section for this pass of 59 Kappa was calculated to be 226 square feet from this record. The rather detailed treatment of this one pass of 59 Kappa has been given to illustrate the detailed nature, quantity, and quality of the data that are provided by the DOPLOC satellite tracking system from a single pass recorded by a single receiving station.

23

E. Multiple Antenna Records

The previous discussion of experimental results has been largely devoted to data received by the vertically directed center antenna. Figure 63 shows a similar Doppler record of a satellite signal received by the north antenna and later by the center antenna. The Doppler frequency has a low value and is nearly constant during transit through the north antenna beam which is directed 20 degrees above the horizon. During this interval the Doppler corresponds to the flat portion of the "S" curve. The region between the satellite signal in the north and the center antenna is of interest in this record since it represents a period of unusually high spurious signal activity. The short, steep slope lines are typical of meteor head echoes, and are easily distinguished from the satellite record either by their steep slope or their very short duration AGC record (one second or less). Two of the slopes are of opposite sign to those of the satellite record due to the extremely high velocity of the meteor, which places the Doppler frequency on the opposite side of the heterodyne frequency.

Optimum performance of the DOPLOC system is shown in Figure 80, which is a record of a satellite passing through the three antenna beams successively. This record depicts the step-scan frequency search, the lock-on, and the continuous track sequence as the satellite passed through the north antenna beam, the center beam and the south beam. It can be seen that the 4 kc/s scan range is switched up as soon as the satellite signal has ended in each antenna. This operation is performed manually by the operator who is visually monitoring the ALO output. This record is of particular interest since it is the last revolution of 1960 Delta over the Northern Hemisphere. During the latter part of this revolution, this satellite re-entered the earth's atmosphere over the Southern Hemisphere.

F. Meteor's

In addition to the satellite Doppler frequency record in Figure 60, other short lines of about one second duration are evident in the upper portion of the chart. These are spurious responses due to strong noise

pulses or meteor head echoes. It is significant to note that a spurious frequency signal occurred just a few tenths of a second prior to the satellite Doppler signal reception, yet the ALO was able to respond with full sensitivity to the desired signal. Spurious signals from meteors are identified by their short time duration and steep slopes. Signal reflections from meteor trails, which are large ionized columns moving at very low velocities, are recorded as nearly constant frequency, called "flats", which are close to or equal to the bias frequency.

G. Satellite Trails

There is some indication that the passage of a satellite through the ionsphere produces a cloud of ionized particles in its wake, [1,2,3,] causing a constant frequency reflection similar to the "flat" reflections produced by meteor trails. The existence of such an ionized cloud is further supported by data as shown in Figures 16 and 18, where a "flat" is seen immediately following the Doppler reflection from 58 Delta. Other constant frequency reflections appearing after a satellite pass may be seen in Figures 26, 27, 30, 66, 89, 92 and 100.

Figure 15 shows an interesting example of a satellite pass occurring simultaneously with a "flat". Revolution 8386 of 58 Delta was detected three seconds after the constant frequency reflection was observed. This example demonstrates the ability of the DOPLOC system to detect and track a satellite in the presence of a large, interfering signal.

H. Predictions

Satellite predictions computed and distributed by Space Track Control Center were used to determine base line crossing times for known satellites. Two chart speeds were used for the analog recordings; 2.5 mm/second during specifically selected search periods when a satellite was predicted to cross the DOPLOC base line and 1 mm/second at all other times during routine surveillance.

Not every satellite known to have passed between the transmitter and receiver was detected, apparently because of insufficient reflected signal

due to satellite attitude at the time it traversed the antenna beam. For the same reason, many passes were detected by one or two antennas but not by all three antennas. These one or two-antenna reflections prove extremely useful, however, when examined in conjunction with the three-antenna data, in analysis and comparison of cross sectional areas, "signature", satellite attitude changes (spin and tumble) and scintillation.

IV. REFLECTION CROSS SECTIONS AND POWER RATIOS

As previously stated, the Doppler frequency vs time data are digitally recorded at the receiving station as the satellite passes through the antenna beam. From these data, we may calculate the Doppler slope (rate of change of Doppler frequency) and, subsequently, the altitude and east-west position of the satellite as it crossed the base line joining the transmitter and receiver. Using these values and the method described in Appendix I, we calculate the power ratio[*] (ratio of calculated received power to measured received power) and the apparent cross section observed for each satellite pass through each antenna beam. Table 4 presents these values.

Before calculating the cross section and power ratio for a specific satellite it is necessary to estimate the dimensions of the satellite and calculate the power that would be radiated from an object of this size, assuming it were located at a point in space corresponding to the satellite position (altitude and east-west location). Subsequently, when the true measured power is determined using the actual received signal amplitude reflected from the satellite, the ratio of calculated power to measured power gives the power ratio. Since all the reflected power readings from one satellite are compared to the calculated value for that satellite alone, we are permitted to examine the individual power ratios as a composite group, regardless of the satellite from which they were determined. In other words, a power ratio of 1 indicates that the measured power equals the calculated power, regardless of the physical size of the satellite involved. Figures 115, 116, and 117 present the power ratios measured in the center, north and south antennas, respectively, and Figure 118 shows all the ratios, regardless of antenna.

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[*] A power ratio value of 1 indicates that the measured power equals the calculated power; a value of 10 indicates the measured power equals 1/10 of the calculated power.

TABLE 4

CROSS SECTION AND POWER RATIO SUMMARY

Satellite Name	Rev. Number	Center Antenna		North Antenna		South Antenna	
		Cross Section Sq. Ft.	Power Ratio*	Cross Section Sq. Ft.	Power Ratio	Cross Section Sq. Ft.	Power Ratio
58 Delta	6844	Rerun**	-	-	-	-	-
	7049	86.0	3.9	-	-	-	-
	7358	47.0	6.4	-	-	-	-
	8336	68.5	4.4	-	-	-	-
	8643	25.6	10.3	-	-	-	-
	8683	87.9	3.4	-	-	-	-
	8719	27.1	11.0	-	-	-	-
	8734	28.2	11.0	-	-	-	-
	8795	15.1	19.9	-	-	-	-
	9009	40.5	7.4	-	-	-	-
	9172	49.0	6.1	-	-	-	-
	9255	178.2	2.3	-	-	-	-
	9286	248.0	1.2	-	-	-	-
	9466	87.1	3.5	-	-	-	-
	9472	292.0	1.0	-	-	-	-
	9503	22.9	13.1	-	-	-	-
	9581	38.0	7.9	-	-	-	-
	9612	-	-	-	-	-	-
	9716	16.2	20.2	52.4	6.3	-	-
	9722	-	-	-	-	-	-
	9826	12.7	25.8	-	-	24.9	13.1
	9832	7.1	14.2	-	-	-	-
	9842	-	-	-	-	25.1	13.0
	9848	22.3	14.7	75.7	4.3	-	-
	9905	-	-	-	-	24.2	13.5
	9927	-	-	137.2	2.4	43.0	7.6
	9957	180.0	1.8	112.1	2.9	-	-
	9943	74.5	4.4	66.6	4.8	198.6	1.6

28

TABLE 4 (Continued)

Satellite Name	Rev. Number	Center Antenna		North Antenna		South Antenna	
		Cross Section Sq. Ft.	Power Ratio	Cross Section Sq. Ft.	Power Ratio	Cross Section Sq. Ft.	Power Ratio
58 Delta	9959	-	-	140.0	2.3	-	-
	9975	-	-	31.8	10.2	-	-
	9991	-	-	43.4	7.5	-	-
	10001	29.6	11.1	-	-	60.0	5.5
	10007	-	-	96.7	3.4	-	-
	10023	-	-	14.0	23.3	-	-
59 Epsilon	53	26.6	25.9	-	-	-	-
	60	18.8	38.0	-	-	-	-
	121	-	-	-	-	53.5	12.9
	314	14.7	46.3	-	-	-	-
	414	70.2	9.8	-	-	-	-
	438	Rerun**	-	-	-	Rerun**	-
	532	-	-	-	-	-	-
59 Zeta	14	132.0	5.2	-	-	-	-
	150	-	-	-	-	-	-
	241	Rerun**	-	-	-	97.0	7.1
	556	27.7	24.7	-	-	-	-
	855	59.3	11.6	-	-	-	-
	871	51.2	13.4	-	-	-	-
	887	151.2	4.6	-	-	-	-
59 Kappa	183	225.6	3.1	-	-	-	-

29

TABLE 4 (Continued)

Satellite Name	Rev. Number	Center Antenna		North Antenna		South Antenna	
		Cross Section Sq. Ft.	Power Ratio	Cross Section Sq. Ft.	Power Ratio	Cross Section Sq. Ft.	Power Ratio
59 Lambda	96	102.2	6.4	-	-	-	-
	138	60.5	11.4	-	-	-	-
	278	149.8	4.6	-	-	-	-
	685	Rerun**	-	Rerun**	-	33.6	20.5
	1285	174.4	3.9	-	-	-	-
	1516	72.9	9.4	-	-	-	-
60 Gamma 1	318	94.5	3.5	-	-	-	-
	403	63.3	5.2	-	-	-	-
	418	46.4	8.0	-	-	-	-
	836	118.0	2.7	-	-	-	-
	960	97.1	3.4	-	-	-	-
60 Gamma 2	1042	32.4	10.1	-	-	-	-
60 Delta	30	35.9	19.2	49.7	6.6	20.3	16.1
	61	-	-	24.3	13.4	90.9	3.6
	117	-	-	-	-	178.2	1.8
	124	53.1	12.7	302.3	1.1	17.0	19.2
	140	20.9	32.7	321.2	1.0	123.3	2.7
	156	10.6	62.6	296.7	1.1	20.2	16.2
	165	71.5	9.7	298.2	1.1	164.6	2.0
	172	210.0	3.3	37.2	8.8	69.8	4.7

TABLE 4 (Continued)

Satellite Name	Rev. Number	Center Antenna Cross Section Sq. Ft.	Power Ratio	North Antenna Cross Section Sq. Ft.	Power Ratio	South Antenna Cross Section Sq. Ft.	Power Ratio
60 Epsilon 1	53	-	-	18.8	17.0	297.1	1.1
	99	-	-	-	-	-	-
	150	303.7	1.1	-	-	296.1	1.1
	165	81.0	4.0	-	-	-	-
	386	206.1	1.6	-	-	-	-
	522	-	-	-	-	-	-
60 Epsilon 2	106	-	-	-	-	111.3	2.9
	137	23.5	13.9	-	-	-	-
	147	14.0	23.4	303.6	1.1	74.3	4.4
	153	-	-	-	-	-	-
	194	14.0	23.4	121.2	2.7	-	-
	303	96.2	3.4	-	-	-	-
	309	-	-	-	-	-	-
	356	-	-	314.3	1.0	-	-
	617	6.2	52.3	-	-	-	-
60 Epsilon 3	280	112.0	2.9	-	-	-	-
60 Epsilon 4	280	23.7	13.8	-	-	-	-
60 Epsilon 5	569	82.5	3.9	-	-	-	-
60 Epsilon 6	265	227.0	1.4	-	-	-	-
	301	14.2	23.1	-	-	-	-

*Calculated power divided by measured power.

**Not calculated since original signal not acquired by ALO. Pass was recovered from magnetic tape playback and original signal strength calibrations are not valid.

31

It is noted that 45% of the ratios in Figure 118 occur between 1 and 5, and that slightly more than 80% are between 1 and 15. This means that almost half of the reflections possess a power value which is 1/5 of the calculated value or larger, while 8 out of 10 reflections are 1/15 the calculated value or larger.

An interesting situation exists in connection with the cross sections measured for 60 Delta (see Table 4). Of the eight passes received, six passes were three-antenna reflections, offering an excellent opportunity for comparison of cross sections as measured by the different antennas. It is also noted that, of the six three-antenna passes, five passes exhibited the largest cross section in the north antenna, and four passes were almost equal to the calculated value, as indicated by the power ratio approaching unity (Revolutions 124, 140, 156, and 165). No clear cut explanation can be presented for this preponderance of large cross sections in the north antenna. All the antennas were identical in configuration, dimensions and operating specifications, and all were oriented with reference to a first-order geodetic survey. Subsequent to installation, a signal generator was mounted in an airplane and a series of flights were made over the antenna field at each station. In this manner, the radiation patterns and antenna alignments were measured and determined to be optimum. Thus, it would appear that each of the antennas should "see" a satellite in the same way, and any variance in apparent size from one antenna to another would be purely random, dependent solely on such variables as satellite altitude, east-west location, and attitude. The observed cross sections for 60 Delta do not appear random, however.

Further examination of the data, specifically Table 5 which presents average values for all cross sections and power ratios, indicates that in three of the four instances where a comparison can be made between the three antennas for one satellite (58 Delta, 60 Delta, 60 Epsilon 1 and 60 Epsilon 2), the largest average cross section is that measured by the north antenna. Since it appears that the north antennas consistently produced larger power and cross section values, we might conclude that the north antennas were perfectly aligned, or possessed greater gain than either the center or south antennas.

32

TABLE 5

AVERAGE VALUES OF CROSS SECTIONS AND POWER RATIOS

Satellite Name	Number of Observations			Center Antenna		North Antenna		South Antenna		All Antennas	
	Center	North	South	Cross Section Sq. Ft.	Power Ratio	Cross Section Sq. Ft.	Power Ratio	Cross Section Sq. Ft.	Power Ratio	Cross Section Sq. Ft.	Power Ratio
58 Delta	23	10	6	73.2	8.9	77.0	6.7	62.6	9.1	72.5	8.4
59 Epsilon	4	0	1	32.6	30.0	-	-	53.5	12.9	36.8	26.6
59 Zeta	5	0	1	84.3	11.9	-	-	97.0	7.1	86.4	11.1
59 Kappa	1	0	0	225.6	3.2	-	-	-	-	225.6	3.1
59 Lambda	5	0	1	112.0	7.1	-	-	93.6	20.5	98.9	9.4
60 Gamma 1	5	0	0	83.9	4.6	-	-	-	-	83.9	4.6
60 Gamma 2	1	0	0	32.4	10.1	-	-	-	-	32.4	10.7
60 Delta	6	7	8	67.0	23.4	189.9	4.7	85.5	8.3	115.0	11.
60 Epsilon 1	3	1	2	196.9	2.2	18.8	17.0	296.6	1.1	200.5	4..
60 Epsilon 2	5	3	2	50.8	23.3	246.4	1.6	92.8	3.7	107.9	12.9
60 Epsilon 3	1	0	0	112.0	2.9	-	-	-	-	112.0	2.9
60 Epsilon 4	1	0	0	23.7	12.8	-	-	-	-	23.7	13.8
60 Epsilon 5	1	0	0	82.5	3.9	-	-	-	-	82.5	3.9
60 Epsilon 6	2	0	0	120.6	12.3	-	-	-	-	120.6	12.3

As soon as we make this tentative assumption, however, we are
faced with contradictory data as observed for 60 Epsilon 1. Table 5
shows six passes of this satellite, three measured by the center antenna,
two by the south and one by the north. Excluding the north antenna pass
for the moment, the five remaining passes combined have an average cross
section of 256.8 square feet and an average power ratio of 1.8. These
values represent the largest average cross section and best average power
ratio of any satellite observed, yet the one pass of this satellite received
by the north antenna has a cross section that is smaller than this average
by a factor of 12. The fact that we observed this one small cross section
in the north antenna is not significant, since a single observation cannot
be considered statistically meaningful. However, it is significant that the
average cross sections for the five passes received by the center and south
antennas are large, nearly equal to the calculated value. Why these two
antennas operated so excellently on this one satellite is a matter of con-
jecture.

Referring again to Table 5, we note that the south antenna produced
average cross sections that were larger in 5 out of 7 instances than those
observed by the center antenna for the same satellite. Here again, it
must be pointed out that 2 of the 5 are based on only one pass each (59
Epsilon and 59 Zeta), and no valid conclusions can be drawn from such a
small amount of data.

V. CROSS SECTION "SIGNATURE" OBSERVATIONS

When the signal strength reflected from a number of passes of one satellite is recorded in analog form, the shape of the observed cross section envelopes may appear very much alike, provided that the satellite attitude remains reasonably constant from pass to pass and that propagation conditions are similar. Under ideal conditions, a particular satellite may consistently produce a unique "signature", thus permitting identification on this basis alone. Others may produce a wide variety of shapes, which appear to possess nothing in common. A satellite with dimensions small compared with the wavelength will generate an approximately semi-circular or semi-elliptical signal strength pattern that is independent of physical configuration. Signal strength changes due to scintillation and attitude change (spin and tumble) are usually present with large satellites which produce a very complex received signal envelope configuration and make "signature" identification difficult.

In general, the DOPLOC records obtained by the center antenna are characterized by a short duration, symmetrical envelope that rises and decays smoothly and possesses a rounded peak, with little or no oscillation visible at any time. The average duration and signal strength of the 67 center antenna measurements are 7.5 seconds and -169.4 dbw. The north and south antennas produced two general shapes; either a semi-circular configuration with a smoothly changing signal level or a semi-rectangular envelope with an abrupt rise and decay and a reasonably constant signal level. Considerable variations, some quite large in amplitude, are usually visible in both types. Signals from the north and south antennas were longer than those from the center antenna, since the beams were directed 20 degrees above the horizon as opposed to the vertical center beam. For the 22 observations in the north antenna the averages are 24.8 seconds and -170.4 dbw, while in the south antenna the averages are 15.7 seconds and -173.6 dbw. The overall averages for the 44 reflections are 20.3 seconds and -172.0 dbw. A discussion of several specific "signatures" follows.

58 Delta - An outstanding example of "signature" is evident in Figures 37 and 40, where a sharp null is prominent on each record approximately 10 seconds after the appearance of the Doppler signal. In both cases the reflection is in the north antenna and the length of record permits easy observation of this characteristic null. A severe signal dropout is evident in Figure 25 and, to a lesser extent, in Figure 22. This may be an indication of "signature". Similarly, a small dip is seen in each of the south antenna portions of Figures 31, 35, 36 and 38, approximately 3 seconds prior to signal loss.

59 Epsilon - There is no clear indication of "signature", despite the prevalence of periodic change in signal level, especially in Figures 48, 50 and 52. This change in signal amplitude is probably caused by satellite attitude change rather than by satellite configuration.

59 Zeta - A sharp spike is easily visible on the leading edge of each of the envelopes in Figures 53, 55, 58 and 59. The latter two records show a periodic change in signal strength, whereas none of the other 59 Zeta records possessed this characteristic. The variations in Figures 58 and 59 are due to attitude change, which apparently commenced (or at least increased in frequency) late in the orbital lifetime of 59 Zeta. Even as late as Revolution 855 (Figure 57), there is no indication of this periodic modulation. It is very evident, however, in Revolutions 871 and 877, the last two DOPLOC observations of this satellite before its re-entry into the earth's atmosphere (estimated by Space Track Control Center to have occurred between Revolutions 964 and 966).

59 Kappa - Only one pass was received for this satellite and it shows no significant features.

59 Lambda - The very abrupt signal loss in the middle of Revolution 96 of 59 Lambda (Figure 61) may be "signature" information, though two factors are present which make this assumption appear somewhat doubtful. First, there is no evidence of this unique signal dropout on any of the other records of 59 Lambda. Secondly, and of greater importance, is the extremely rapid signal decay. It is unlikely that any motion or physical configuration of the satellite could produce such a steep decay curve. The almost instan- taneous decay strongly suggests that equipment failure or propagation phenom- ena, rather than satellite movement or shape, caused this sudden loss of signal.

36

60 Gamma 1 - Another excellent example of "signature" is found in Figures 69, 70, and 71, where the V-shaped peak is easily seen. Figure 67 also shows traces of this shape, but the high altitude of this pass (440 miles) severely attenuated the received signal and prevented this characteristic from being more prominent. This pass was the highest pass recorded by the DOPLOC system during its operation. A further identifying feature in these data for 60 Gamma 1 appears to be the signal losses shown in Figures 68, 69, and 70 which occurred in the middle of the passes where the signal is normally at a maximum. On two of these passes, the tracking filter lost lock completely, but the ALO was able to lock-on again when the signal level increased.

60 Gamma 2 - Only one pass was recorded for this satellite and it displays no significant envelope shape.

60 Delta - Here we see a severe null in both Figure 78 (center) and Figure 79 (north). Once again, the tracking filter lost lock during the former pass but the ALO regained the signal automatically when it became stronger. A hint of a similar null may be visible in both Figure 73 (south) and Figure 78 (south). It is worthwhile to point out that Revolution 61 (Figure 74) was received by the north and south antennas but not by the center antenna. Perhaps the satellite was oriented in its maximum null-producing attitude during the middle portion of this pass and, consequently, this orientation reduced the reflected signal to a level lower than the ALO threshold level and no lock was obtained. Repeated rerunning of the magnetic tape of this pass in an attempt to lock the ALO on the Doppler signal was without success. It appears that the center antenna portion of Revolution 156 (Figure 78) may have been approaching this complete signal fadeout condition also.

60 Epsilon 1 - There does not appear to be any clear indication of "signature" in these data. The record of revolution 150 (Figure 83) exhibits a nine second signal loss in the middle of the pass. The absence of signal dropout in the other records of 60 Epsilon 1 makes it difficult to correlate these data with "signature" information. It may be noted that data shown in Figure 84 was recorded at 1 mm/second which served to

37

condense the envelope. The 2.5 mm/second chart speed would have enlarged the envelope and produced a trace similar to Figure 86.

60 Epsilon 2 - The distinguishing feature here seems to be the oscillations observed in the center antenna portions of Figures 88, 92 93 and 95. Reflections from the majority of other satellites observed in the center antenna are smooth. Again it is noted that the chart speed in Figures 92 and 93 is 1 mm/second, while in Figures 88, 89 and 95 it is 2.5 mm/second. Had the former passes been recorded at 2.5 mm/second, the resulting envelope would be very similar to Figure 95.

60 Epsilon 3, 4, 5 and 6 - It is not possible to evaluate individually these data in terms of "signature", since only one or two passes of each satellite are available and none seems to possess any distinguishing features. Intercomparison is not valid either, even though they are all fragments from 60 Epsilon 1 (Sputnik IV), because the physical configuration of the fragments is probably not the same and, therefore, any similarity in envelope shape would be purely random.

VI. CROSS SECTION MODULATION DUE TO ATTITUDE CHANGE

Evidence of periodic signal modulation, such as might be caused by spin or tumble, is visible in the majority of signal strength records. This cross section modulation is visible both in the records of ground-originated reflected signals and in the records of signals which originate from a satellite-borne transmitter. For this discussion, we shall term the former method of satellite detection and observation "passive" tracking, and the latter method "active" tracking. Measurement and analysis of signal strength modulation observed with the two methods of tracking are difficult for several reasons. Propagation variances alone may introduce periodic changes in observed signal strength which can be mistaken for modulation caused by satellite attitude change. The relatively short duration of the passive records recorded by the center antenna make it impossible to determine a modulation periodicity in this antenna of more than a second or two. The passive records recorded by the north and south antennas, though fewer in number, are of greater value in modulation analysis since they are considerably longer in duration and permit measurement of several cycles of a modulation possessing a period in the order of 1 cycle per 5 seconds or longer. Also, when active tracking records are examined, especially those taken on Sputnik III and IV which transmitted on a nominal frequency of 20 Mc/s, the Faraday effect must be considered. This effect varies inversely with the reciprocal of the frequency squared. Thus, it is definitely a prime factor in producing periodic signal modulation at 20 Mc/s, considerably less a factor at 108 Mc/s (the DOPLOC reflection frequency), and virtually non-existent at still higher frequencies such as the transmitting beacons in the Discoverer satellites. Fluctuations in received signal, while not necessarily periodic, may also be caused by changes in the amplitude of the transmitted signal or the gain of the receiver. Within these limitations, an attempt has been made to analyze the DOPLOC records for evidences of cross section modulation caused by satellite attitude change.

Examination of passive and active records for 58 Delta (Sputnik III) and 60 Epsilon 1 (Sputnik IV) show signal strength nulls occurring in a 2:1 ratio, i.e., two nulls are observed on the passive records for every

null on the active records. Figures 29 (north), 33 (south) and 39 (north) are records of passive reflections from 58 Delta and show an average of 1 null per 3 seconds, while Figure 119, an active record for 58 Delta, displays 1 null per 6 seconds. Similarly, Figures 82 (north), 83 (south), and 85, passive observations of 60 Epsilon 1, show an average of 1 null per 1.5 seconds, and an active record of the same satellite (Figure 120) shows 1 null per 3 seconds. It is evident from these data that the physical configuration of the satellite produces a four-lobed pattern when reflecting the ground-originated DOPLOC signal, whereas the transmitting antennas on the satellite radiate a two-lobed pattern for active tracking. As the satellite tumbles and spins, these radiation patterns produce the 2:1 ratio seen in the signal strength null frequency.

Evidence of similar periodic nulls is seen in the records of 59 Epsilon (Discoverer V). Here, however, the passive to active ratio is 8:1. Figures 48 (south), 50 and 52 (south) are passive reflection records of 59 Epsilon and display an average of 1 null per 3 seconds. Each of two active records for 59 Epsilon, one of which is shown in Figure 121, show 1 null per 24 seconds. Apparently, the cylindrical shape of the Discoverer satellite creates a multi-lobed reflection pattern, while the transmitting antenna radiates the two-lobed pattern. The validity of this assumption regarding the reflection pattern is enhanced by the fact that the length of the cylinder (19.2 feet) is approximately twice the wavelength of the DOPLOC frequency (9.1 feet). Where the length of the reflecting object is large compared to the wavelength, as in this case, the result is a multi-lobed radiation pattern.

It is worthwhile to note that a total of nine active records taken on 59 Zeta and 60 Delta (Discoverer VI and XI) show an average of 1 null per 24 seconds, with individual values ranging from 11 to 40 seconds. The agreement with the null rate observed for 59 Epsilon is striking.

Table 6 summarizes the data discussed above and lists null rates for several other satellites as well.

40

TABLE 6

SIGNAL STRENGTH NULL RATES

Satellite	Passive		Active		Passive-Active Null Ratio
	Number of Observations	Avg. Time Between Nulls secs.	Number of Observations	Avg. Time Between Nulls secs.	
Sputniks					
58 Delta	3	3	1	6	2:1
60 Epsilon 1	3	1.5	2	3	2:1
60 Epsilon 2	6	1.2	(no transmitter)		-
Discoverers					
59 Epsilon	3	3	2	24	8:1
59 Zeta	2	2	7	24	12:1
60 Delta	2	1.8	2	24	13:1

41

VII. SCINTILLATION

A number of the DOPLOC records of reflected signal strength show traces of scintillation and Table 7 presents a summary of the most prominent examples, grouped according to pass time. The estimated peak-to-peak scintillation in db is given for each pass, as well as the antenna in which the reflection was received. A notation is also made concerning the season of the year in which the pass was recorded. Certain qualitative features in the data are rather pronounced and deserve additional comment.

The existence of a diurnal cycle is apparent, with the scintillation amplitude being greater at night than during the day. The average peak-to-peak signal fade for 9 observations made at night is 2.4 db, while for 20 daytime observations the average value is only 1.4 db. Also, the diurnal effect is much more pronounced in summer than in winter, evidenced by the fact that 8 of the 9 night passes occurred in the months between March and October. A series of one-way radar transmission tests conducted by the Bell Telephone Laboratories, at wavelengths ranging from 30 cm to 17 m, revealed corresponding diurnal and seasonal variations.[4] Similarly, tests carried out by Ross A. Hull, with the aid of other radio amateurs, the U. S. Weather Bureau and Harvard University in the 5 to 8 m wavelength region, yielded comparable results.[5,6]

The data in Table 7 show that scintillation occurs more frequently in the north and south antenna reflections than in the center antenna. Considering the total number of reflections received by each antenna, we find scintillation appearing in 45% of the north antenna passes (10 of 22), 41% of the south antenna passes (9 of 22) and only 15% of the center antenna passes (10 of 67). The indication here is that the reflecting and diffracting properties of the terrain and the irregularities of the atmosphere near the earth's surface combine to produce interference waves which, in turn, cause variation in signal strength. These phenomena would heavily influence reflections in the north and south antennas, since they are beamed only 20 degrees above the horizon. The

TABLE 7

SCINTILLATION VS PASS TIME

Satellite Name	Revolution Number	Antenna*	Peak-to-Peak Scintillation in db	Pass Time U. T.	Pass Time C. S. T.	Season**	
60 Epsilon 2	503	C	2.0	0355	2155	S	
60 Delta	117	S	2.0	0628	0028	S	
60 Epsilon 2	19A	N	3.0	0642	0042	S	
58 Delta	9957	N	2.0	0642	0042	S	NIGHT PASSES
58 Delta	2251	S	2.0	0642	0042	S	
58 Delta	6605	C	2.0	0652	0052	W	
58 Delta	9905	S	3.0	0700	0100	S	
60 Epsilon 2	147	N	2.5	0721	0121	S	
58 Delta	9852	N	3.0	0849	0249	S	
60 Epsilon 2	509	C	2.0	1326	0726	S	
58 Delta	8755	C	1.0	1358	0758	W	
60 Epsilon 6	501	C	1.5	1400	0800	S	
58 Delta	8794	C	1.0	1454	0854	W	
59 Lambda	278	N	1.0	1504	0904	W	
58 Delta	8719	C	1.0	1530	0930	W	
58 Delta	9959	N	1.0	1548	0948	S	
58 Delta	9945	N	1.0	1603	1003	S	
58 Delta	6605	C	1.0	1647	1047	W	
59 Zeta	150	S	1.0	1650	1050	W	DAY PASSES
60 Epsilon 2	106	S	1.0	1735	1135	S	
60 Delta	61	N	1.5	1803	1203	S	
58 Delta	9848	S	1.5	1812	1212	S	
58 Delta	6852	S	2.0	1813	1213	S	
60 Delta	50	N	2.0	1840	1240	S	
58 Delta	9722	S	1.5	2045	1445	S	
58 Delta	8386	C	1.0	2136	1536	W	
60 Epsilon 2	617	C	2.0	2218	1618	S	
58 Delta	9612	N	1.0	2219	1619	S	
59 Lambda	685	S	2.0	0016	1816	W	

*S - south, C - center, N - north
**W - winter (November - February)
**S - summer (March - October)

greater length of the observations by the north and south antennas may also contribute to the more frequent observations of signal fade in these antennas.

From an examination of a number of active tracking records made at Aberdeen Proving Ground, Maryland, there appears to be more scintillation present in these active records than in the passive reflection records. Figure 122 shows a Doppler record of 58 Delta obtained at Aberdeen by tracking the 20 Mc/s satellite-borne transmitter. Peak-to-peak signal variations for this record are approximately 6 db, roughly twice as large as any variations noted in the passive records. This satellite was probably experiencing severe buffeting when this recording was made, since re-entry occurred only 30 revolutions later. These drastic oscillations may have increased the scintillation amplitude to some extent, since records taken earlier in the lifetime of 58 Delta show signal fade in the order of 3-4 db. Then too, the very slight Doppler frequency shift during this pass indicates that the satellite was at a great distance from the station and that the inclination of the line of sight to the horizontal was small. Thus, as mentioned previously with respect to scintillation in the north and south antennas, interference waves may have contributed to the increased amplitude of the signal variations.

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REFERENCES

1. J. D. Kraus, "Evidence of Satellite-Induced Ionization Effects Between Hemispheres", Proc. IRE, 48, 1913-1914, (1960).

2. J. D. Kraus, R. C. Higgy, D. J. Scheer and W. R. Crone, "Observations of Ionization Induced by Artificial Earth Satellites", Nature, 185, 520-521, (1960).

3. Roberts and Kirchner, QST, p. 34, (1959).

4. J. C. Schelling, C. R. Burrows, and E. B. Ferrell, "Ultra-short-wave Propagation", Proc. IRE, 21, 427, (1933); C. R. Burrows, A. Decino, and L. E. Hunt, "Ultra-short-wave Propagation over Land", ibid, 33, 1507, (1935); and "Stability of Two-meter Waves", ibid, 26, 516, (1938); C. R. Burrows, A. B. Crawford, and W. W. Mumford, "Ultra-short-wave Transmission over a 39-mile Optical Path", ibid 28, 360, (1940).

5. R. A. Hull, QST, 19, 3, (1935), and 21, 16, (1937).

6. A. W. Friend, Proc. IRE, 33, 358, (1945).

CALCULATION OF POWER RATIO AND CROSS SECTION

Altitude And Ground Range Determination

Center Antenna - As previously stated, the Doppler frequency vs time data are digitally recorded at the receiving station as the satellite passes through each of the three antenna beams. From the digital Doppler data we calculate the Doppler slope (rate of change of Doppler frequency). Knowing the Doppler frequency and slope and assuming circular motion, it is possible to obtain the altitude and east-west location of the satellite as it crosses the base line joining the transmitter and receiver, with the aid of a chart of the type presented in Figure 123. Constant contour lines have been computed and drawn for the Doppler frequency and the time derivative of the frequency (the slope) in the vertical plane containing both the transmitter and receiver. These contours vary with satellite orbital inclination, so that several charts are required for orbits of various inclinations. Each chart is valid, however, only for data received in the center beam. Given a Doppler frequency of 300 cps and a slope of 90 cps^2 at the midpoint of the record, we locate the curves representing these values on the chart and, at their intersection, read an altitude of 177 miles and a sub-satellite point on the base line located 350 miles east of Fort Sill. Having determined these distances, a sketch similar to Figure 124 is prepared to assist in completing the power and cross section calculations.

North and South Antenna - The geometry and calculations necessary to locate the point of intersection of a satellite in the north or south antenna, and its corresponding ground range from Fort Sill, vary somewhat from the method described for the center antenna. In these antennas, the intersection point and its corresponding distance east or west of Fort Sill are functions of satellite altitude, and the inclination of the orbital plane and base line with respect to the equator. For purposes

of this discussion, we shall confine ourselves to the south antenna. Calculations in the north antenna are similar. Figure 125 gives a graphic presentation of the geometry involved.

The south antenna is elevated 20 degrees above the horizon and oriented in azimuth as shown in Figure 11. The altitude of the satellite intersection point in the center antenna is taken as the height of the point of intersection in the south antenna pattern. The curvature of the earth is ignored here since it is negligible over the relatively short distance involved. Referring to Figure 125, we calculate X, the perpendicular distance from the base line to the point of intersection of the satellite in the south antenna, using the trigonometric function

$$X = \frac{z}{\sin 20^\circ}$$

Subsequently, the perpendicular distance Y, from the 20 degree plane of the south antenna to the 90 degree plane of the center antenna is determined by

$$Y = \frac{z}{\tan 20^\circ}$$

The next step is to calculate θ_i, the angle at which the satellite crosses the base line. If we let i equal the orbital inclination at the equator and i' the orbital inclination at any North Latitude ϕ, then

$$\cos i' = \frac{\cos i}{\cos \phi}$$

Solving for i' gives the angle at which the satellite crosses the particular North Latitude ϕ. The Forrest City - Fort Sill base line is a segment of a great circle which is not parallel to the equator; hence as shown in Figure 126, the satellite crosses the base line at an angle different from i', the difference being equal to the inclination of the base line to the equator. The base line is inclined 3 degrees to the equator so, for a north-south pass 3 degrees must be added to i', while for a south-north pass 3 degrees is subtracted from i' to obtain θ_i.

48

Finally, knowing θ_1 and Y, the distance d moved along the base line in Figure 125 can be determined by the trigonometric relation

$$\tan \theta_1 = \frac{Y}{d} \cdot$$

This value d must be added to or subtracted from r (the ground range from Fort Sill as determined for satellite intersection in the center antenna), depending on the pass direction and the antenna involved. As shown in Figure 127, for a north-south pass, ground range in the north antenna is equal to r - d, while for the same pass in the south antenna the ground range is r + d.

Having thus determined the distance from the base line to the satellite intersection point in the 20 degree plane and the corresponding ground range from Fort Sill, a sketch is prepared as shown in Figure 128 to aid in completing the calculations.

Power and Cross Section Calculations

Having determined satellite altitude (or the perpendicular distance from the base line to the point of intersection in the 20 degree plane), as well as the ground range east or west of Fort Sill, and knowing that the distance between the transmitter and receiver is 435 miles, the distances R_1 and R_2 and the angles α and β can be computed using standard trigonometric functions (refer to Figures 124 and 128). The azimuth angles of the transmitting and receiving antennas are known (see Figure 11); hence the angles γ and δ can be determined and, from the curve presented in Figure 129, the factors F_T and F_R, which are decimal representations for the angles γ and δ, are obtained. It is now possible to proceed with the computation of the calculated power P_R, the measured power received P_M, the power ratio P_R/P_M, and the apparent cross section of the reflecting object $\sum$.

The calculated power in watts that would be radiated from an object of known dimensions at a given distance from the transmitter and receiver is determined first. For example, a length of 20 feet and a radius of 2.5 feet is assumed for the Discoverer satellite. The maximum reflection

cross section that an object having these dimensions would present is calculated by using the formula [1]

$$\sum = 2\pi \frac{r\ell^2}{\lambda}$$

where λ at 108 Mc/s is 9.1 feet. Solving for $\sum$, a value of 690 square feet is obtained for the Discoverer satellite. Admittedly, this process is an approximation, since accurate determination of $\sum$ is dependent upon r and ℓ being large compared to λ. Similar estimates of physical dimensions were made for Sputnik III and IV and for Transit I, and the resulting values of $\sum$ were used in the calculations pertaining to those satellites. Using the basic radar equation,

$$P_R = \frac{P_T \, G_T \, G_R \, \lambda^2 \, F_T \, F_R \sum}{(4\pi)^3 \, (R_1)^2 \, (R_2)^2} \tag{1}$$

the value of $\sum$ and the following DOPLOC system constants are inserted:

$$P_T = \text{power transmitted} = 40 \text{ kw}$$

$$G_R = G_T = \text{antenna gain in power} = 40$$

$$\lambda = 9.1 \text{ feet}$$

Thus, equation (1) becomes

$$P_R = \frac{1.86 \times 10^8 \, F_T \, F_R}{(R_1)^2 \, (R_2)^2} \tag{2}$$

where R_1 and R_2 are expressed in feet or

$$P_R = \frac{2.41 \times 10^{-6} \, F_T \, F_R}{(R_1)^2 \, (R_2)^2} \tag{3}$$

where R_1 and R_2 are expressed in miles.

Next, equation (3) is solved for P_R to determine the power in watts that would be radiated from an object of this size if it were located at the point in space occupied by the satellite.

To determine the measured received power in watts, the peak of the received signal recorded in db below unity S/N at receiver output is converted to a voltage ratio X.

[1] Ridenour, L., "Radar System Engineering", MIT Radiation Laboratory Series No. 1, p. 66. (1947).

$$X = \frac{\log^{-1}(\text{max db})}{20}$$

If E_1 is the received signal for a 1:1 S/N ratio at the receiver output (which for the DOPLOC system is 0.07 microvolts) and E_2 is the measured received signal voltage, the measured power in watts is

$$P_M = \frac{(E_2)^2}{R}$$

where R, the antenna resistance, is equal to 50 ohms. The power ratio, P_R/P_M expresses the relation between calculated and measured power.

To calculate the cross section corresponding to the peak signal received, equation (1) is used to solve for $\sum$.

After substituting P_M for P_R, equation (1) may be rearranged to give

$$\sum = \frac{P_M (R_1)^2 (R_2)^2}{3.49 \times 10^{-9} \ F_T \ F_R}$$

Solving for $\sum$ gives the apparent cross section of the reflecting object in square feet.

APPENDIX II

BRL-DOPLOC REPORTS

No. 1

BRL Memo Report No. 1055 - October 1958
"Doppler Signals and Antenna Orientation for a Doppler System"
by L. P. Bolgiano, Jr.

CONFIDENTIAL

No. 2

BRL Memo Report No. 1185 - January 1959
First Semi-Annual Technical Summary Report
Period 1 July 1958 - 31 December 1958
by L. G. deBey, V. W. Richard, A. H. Hodge, R. B. Patton, C. L. Adams

(BML 39-60)   CONFIDENTIAL

No. 3

BRL Tech Note No. 1265 - June 1959
"Orbital Data Handling and Presentation"
by R. E. A. Putnam

UNCLASSIFIED

No. 4

BRL Tech Note No. 1266 - July 1959
"An Approach to the Doppler Dark Satellite Detection Problem"
by L. G. deBey

CONFIDENTIAL

No. 5

BRL Memo Report No. 1220 - July 1959
Second Semi-Annual Technical Summary Report
Period 1 January - 30 June 1959
by L. G. deBey, V. W. Richard and R. B. Patton

(BML 208-59)   CONFIDENTIAL

No. 6

BRL Tech Note No. 1278 - September 1959
"Synchronization of Tracking Antennas"
by R. E. A. Putnam

UNCLASSIFIED

No. 7

BRL Memo Report No. 1237 - September 1959
"A Method of Solution for the Determination of Satellite Orbital Parameters
from DOPLOC Measurements"
by R. B. Patton, Jr.

UNCLASSIFIED

No. 8

BRL Memo Report No. 1093 - March 1960
"The Dynamic Characteristics of Phase-Lock Receivers"
by Dr. Keats Pullen

UNCLASSIFIED

No. 9

"Station Geometry Studies for the DOPLOC System"
Stanford Research Institute

UNCLASSIFIED

No. 10

Final Report, Part B, Stanford Research Institute - July 1960
"DOPLOC System Studies"
by W. E. Scharfman, H. Rothman, H. Guthart, T. Morita

UNCLASSIFIED

No. 11

Philco Corporation - 4 May 1960
"Polystation Doppler System"

UNCLASSIFIED

No. 12

Space Science Laboratory, General Electric Co. - October 1960
"Orbit Determination of a Non-Transmitting Satellite Using Doppler
Tracking Data"
by Dr. Paul B. Richards

UNCLASSIFIED

No. 13

Final Technical Report - University of Delaware - June 15, 1960
"Quantum Mechanical Analysis of Radio Frequency Radiation"
by L. P. Bolgiano, Jr. and W. M. Gottschalk

UNCLASSIFIED

No. 14

Final Report F/157, Columbia University - February 11, 1960
"Summary of the Preliminary Study of the Applicability of the Ordir
System Techniques to the Tracking of Passive Satellites"

UNCLASSIFIED

No. 15

BRL Report No. 1110 - June 1960
"Precision Frequency Measurement of Noisy Doppler Signals"
by W. A. Dean

UNCLASSIFIED

No. 16

Third Technical Summary Report - Period July 1959 through June 30, 1960
BRL Memo Report No. 1287
by A. L. G. deBey

UNCLASSIFIED

No. 17

Columbia University Tech. Report No. T-1/157 - August 1, 1959
"The Theory of Phase Synchronization of Oscillators with Application
to the DOPLOC Tracking Filter"
by E. Kreindler

UNCLASSIFIED

No. 18

BRL Tech Note No. 1345 - August 1960
"DOPLOC Receiver for Use with Circulating Memory Filter"
by K. Patterson

UNCLASSIFIED

No. 19

BRL Tech Note No. 1354 - October 1960
"Parametric Pre-Amplifier Results"
by K. Patterson

UNCLASSIFIED

No. 20

BRL Tech Note No. 1367 - December 1960
"Data Generation and Handling for Scanning DOPLOC System"
by Ralph E. A. Putnam

UNCLASSIFIED

No. 21

BRL Report No. 1123 - January 1961
"The DOPLOC Instrumentation System for Satellite Tracking"
by C. L. Adams

UNCLASSIFIED

No. 22

BRL Memo Report No. 1330 - March 1961
"DOPLOC Observations of Reflection Cross Section of Satellites"
by H. T. Lootens

UNCLASSIFIED

In Preparation

"DOPLOC Comb Filter" by R. Vitek

"DOPLOC Orbit Determination Methods" by R. Patton, Jr.

"Final Summary Report on the BRL-DOPLOC Project" by Dr. A. H. Hodge
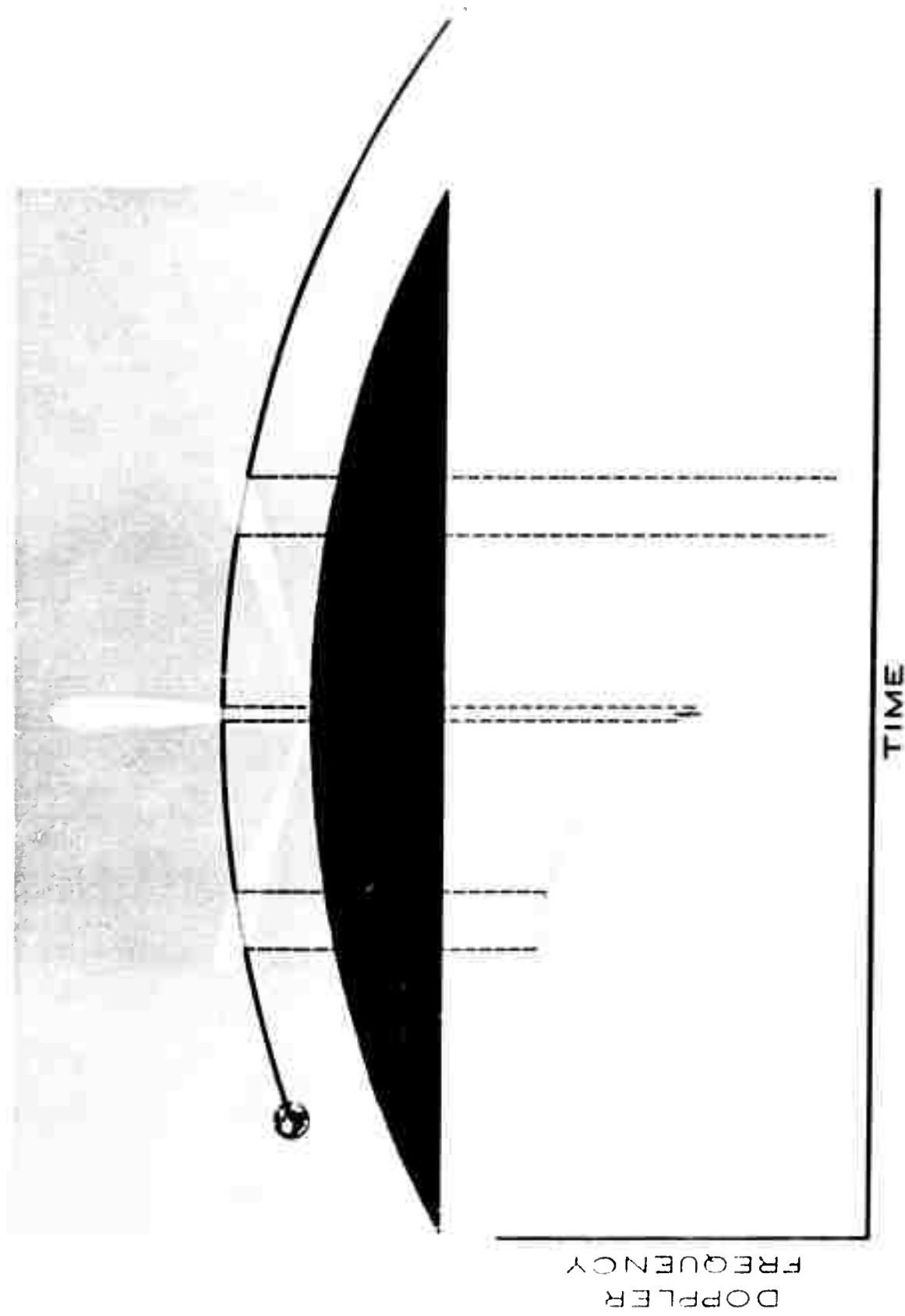
BASIC INTERIM DOPLOC SYSTEM

Fig. 1

TIME

DOPPLER FREQUENCY

Fig. 2   BLOCK DIAGRAM OF R.F. SECTION IN DOPLOC STATION
PASSIVE TRACKING AT 108 MC

58

Fig. 3 BLOCK DIAGRAM OF DOPLOC TIMING SYSTEM
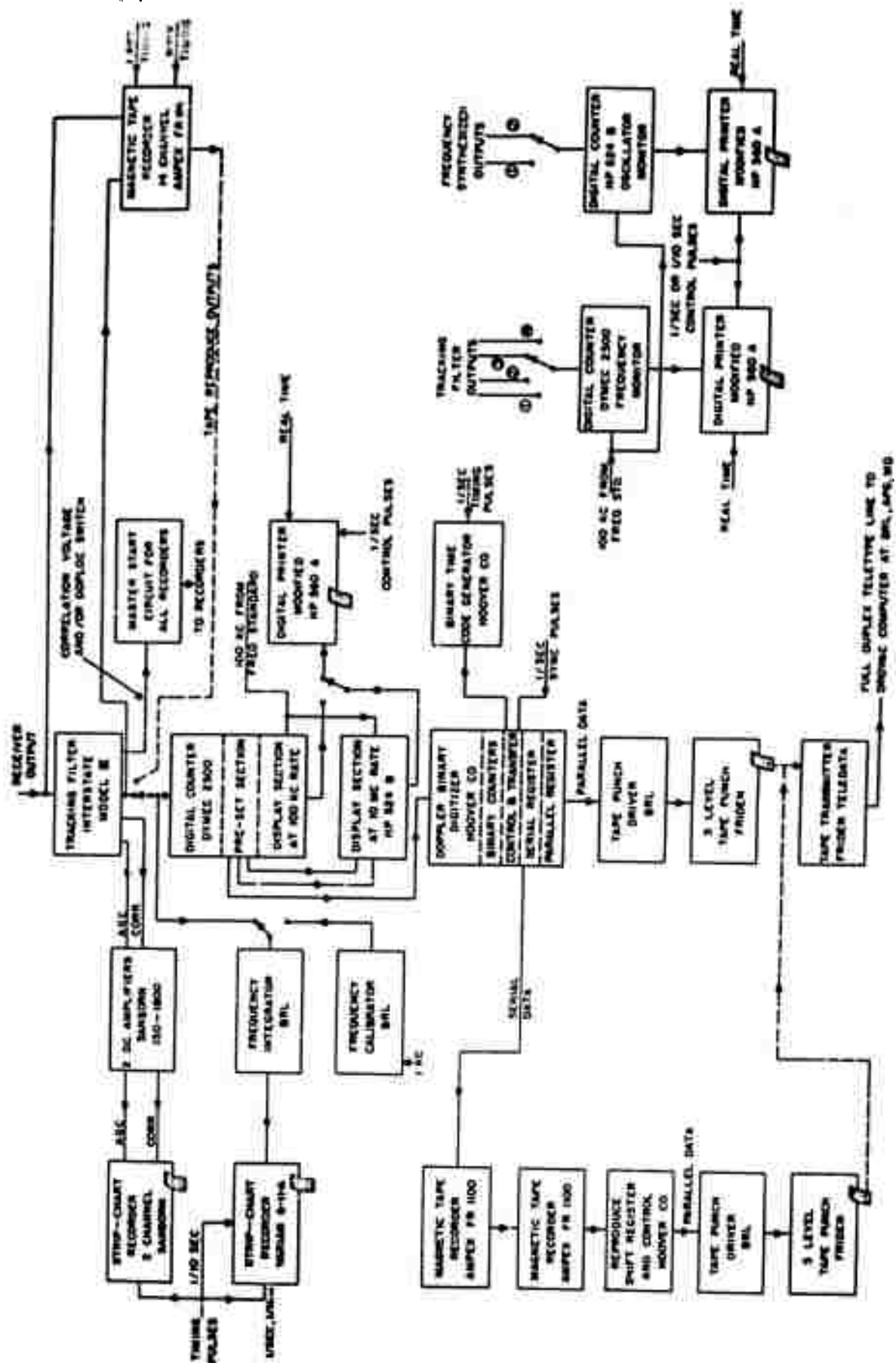
Fig. 4   BLOCK DIAGRAM OF DOPPLER DATA RECORDING SYSTEM FOR A SINGLE CHANNEL

Fig. 5   BLOCK DIAGRAM OF AUTOMATIC LOCK-ON SYSTEM

TYPICAL DOPLOC DATA OUTPUT

Fig. 7

BRL-ARPA DOPLOC SATELLITE FENCE

FIG. 6

THIS DRAWING SHOWS THE VERTICAL CENTER BEAM ONLY. SIMILARLY SHAPED BEAMS DIRECTED 20° ABOVE NORTH AND SOUTH HORIZON NOT SHOWN.

BRL COMPUTATION CENTER

FILTER CENTER

USER

FORREST CITY

FT. SILL

WHITE SANDS MISSILE RANGE
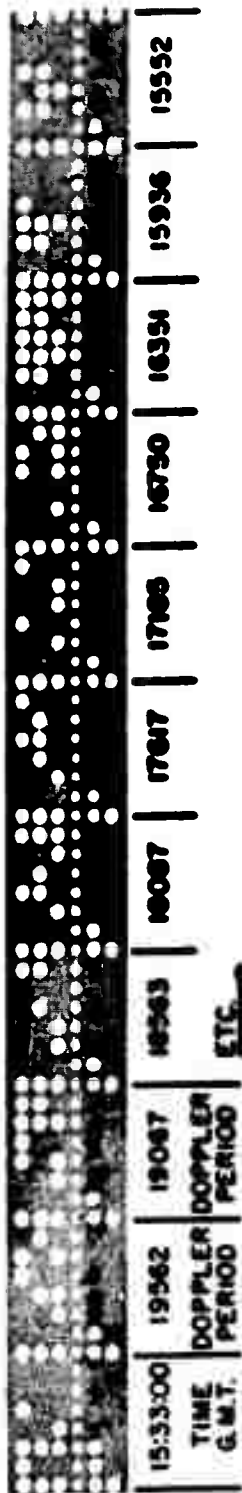
BINARY CODED PUNCHED TAPE

TIME G.M.T.	DOPPLER PERIOD	DOPPLER PERIOD	ETC.
15:33:00	19562	19087	18563	18087	18067	17747	17760	16750	16354	15956	15552

TYPICAL DOPLOC DATA OUTPUT

Fig. 7

63
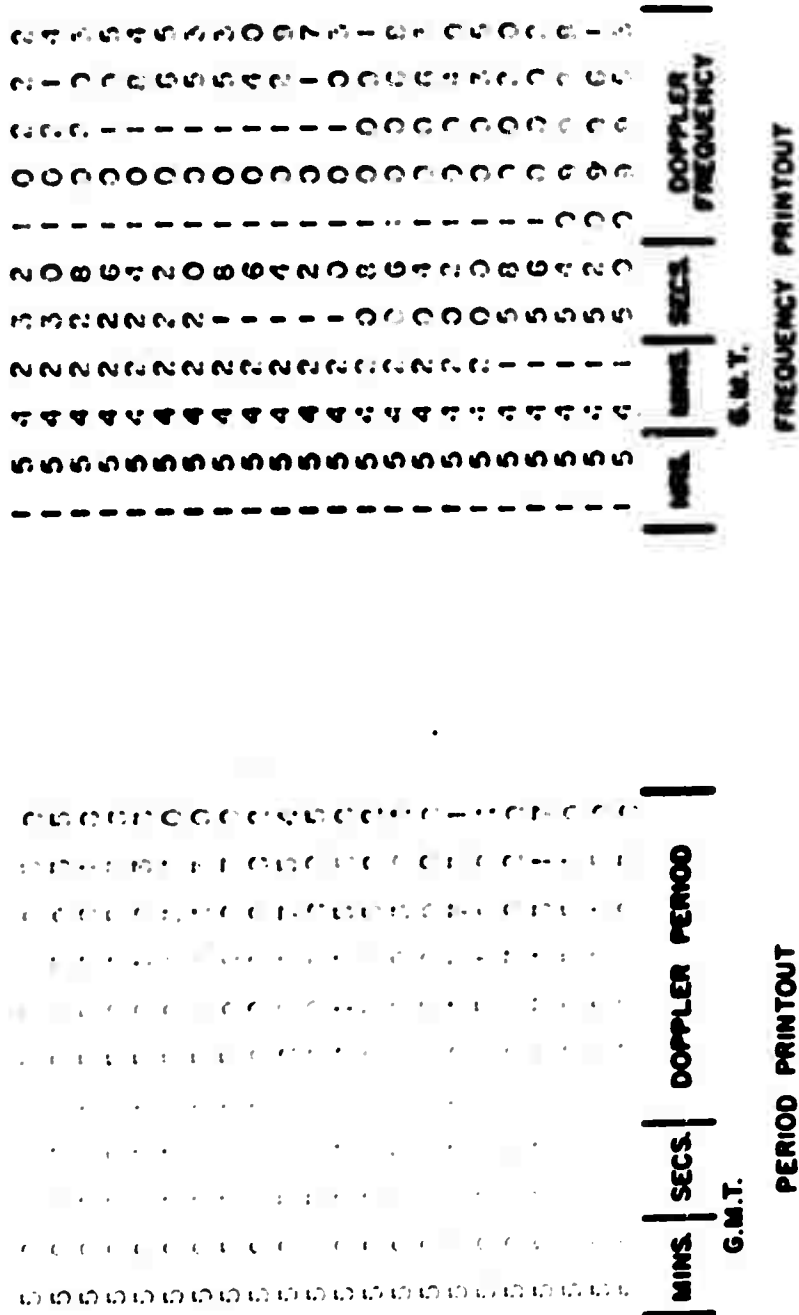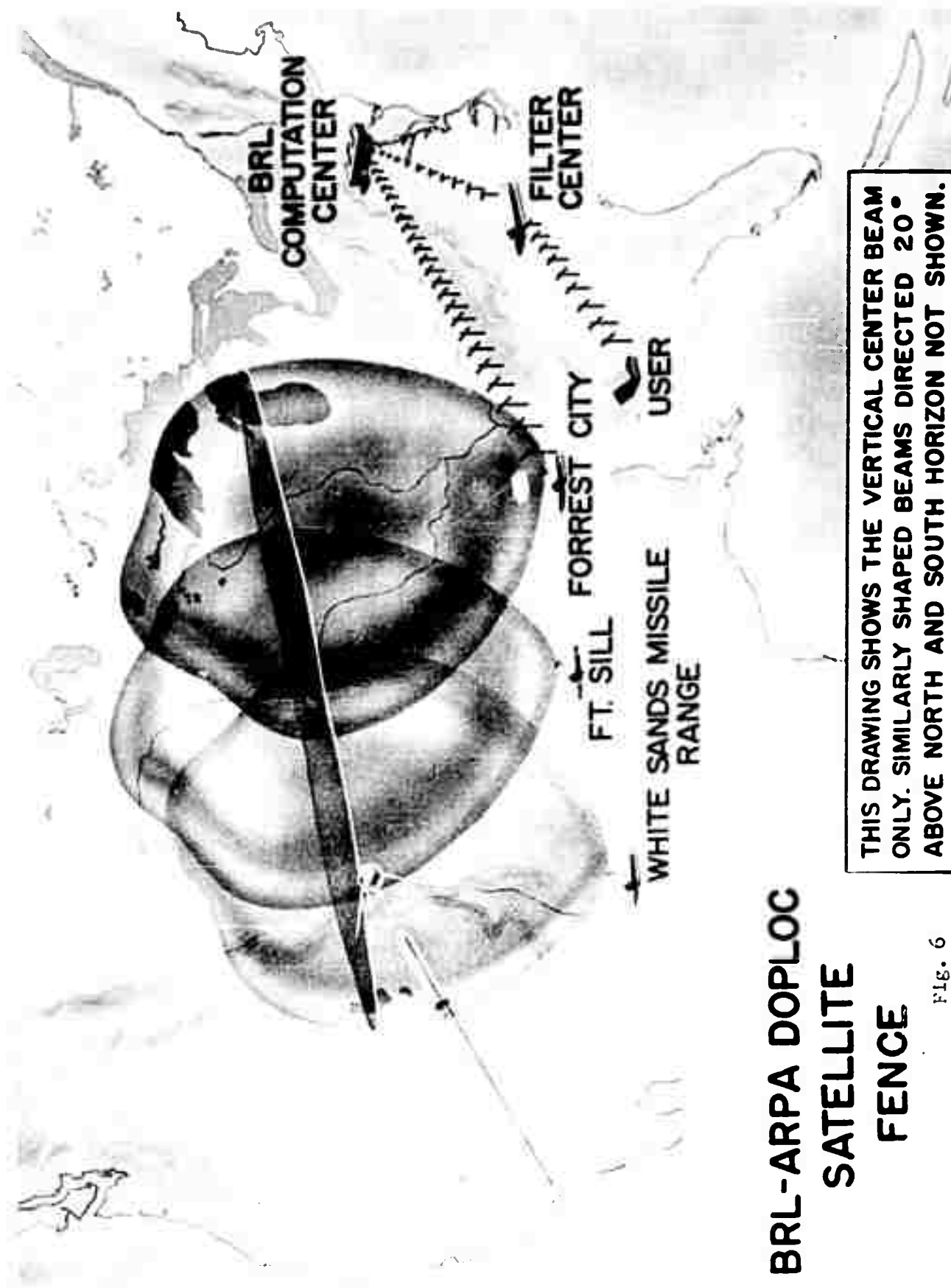
TYPICAL SINGLE PASS DOPPLER ORBIT SOLUTION

(BY ARMY–DOPLOC SATELLITE TRACKING SYSTEM)
REVOLUTION NO. 30 OF 1960 DELTA (DISCOVERER XI)

PERIGEE

APOGEE
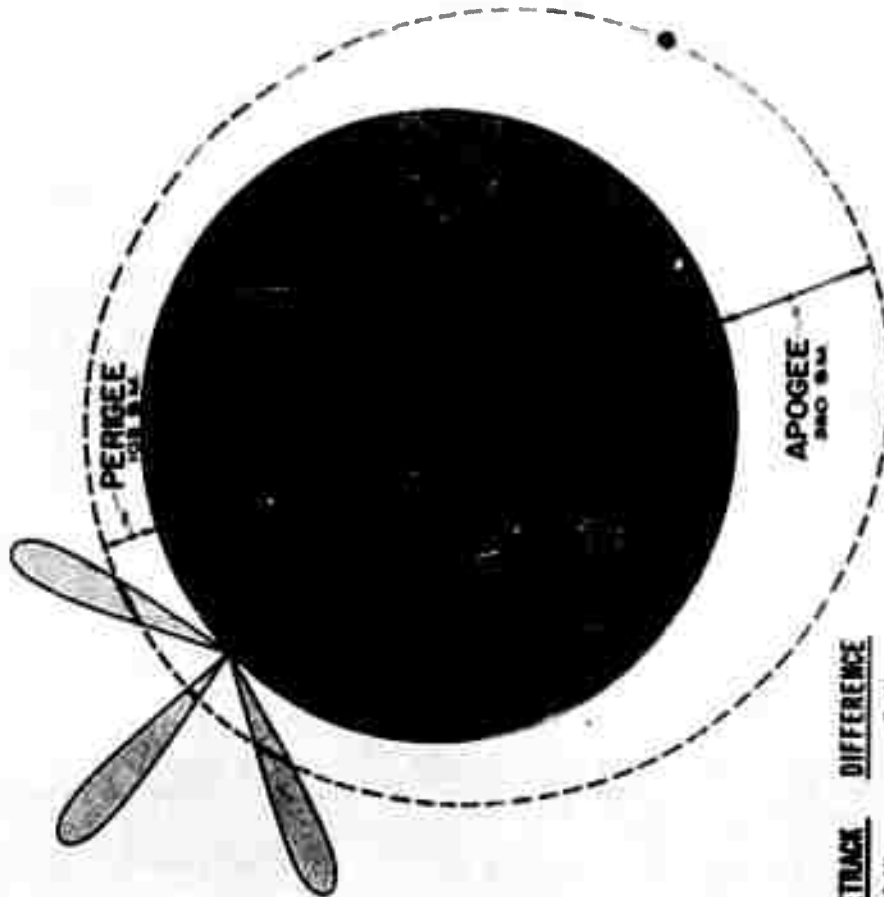
Fig. 8

ORBITAL PARAMETERS	DOPLOC	SPACETRACK	DIFFERENCE
SEMI MAJOR AXIS	4186 MI.	4189 MI.	−3 MI.
ECCENTRICITY	0.0295	0.0291	0.0004
INCLINATION	80.15°	80.01°	0.14°
RIGHT ASCENSION OF ASCENDING NODE	25.92°	25.84°	.08°
ARGUMENT OF PERIGEE	154.96°	146.28°	8.68°
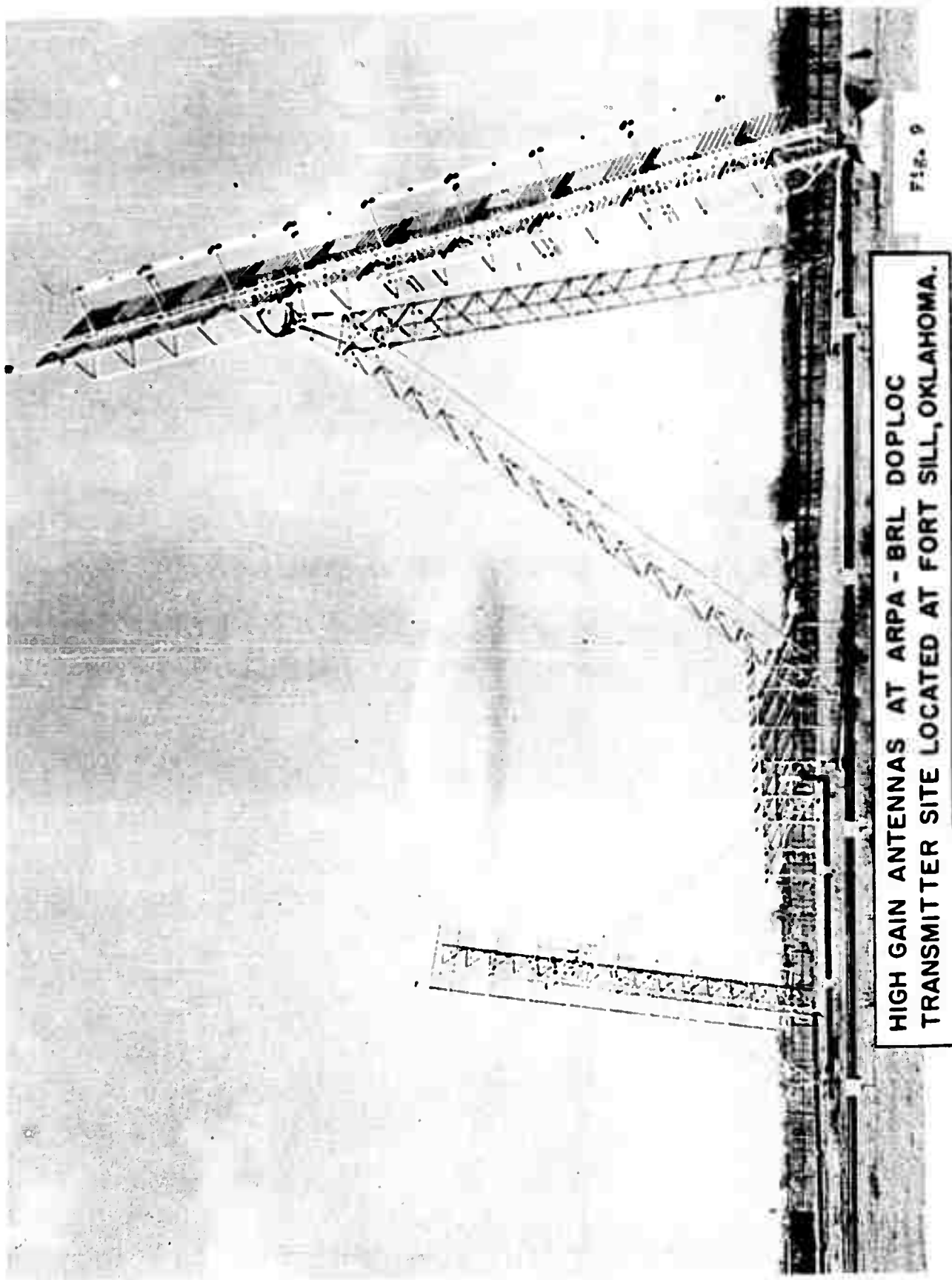
HIGH GAIN ANTENNAS AT ARPA - BRL DOPLOC TRANSMITTER SITE LOCATED AT FORT SILL, OKLAHOMA.

Fig. 9
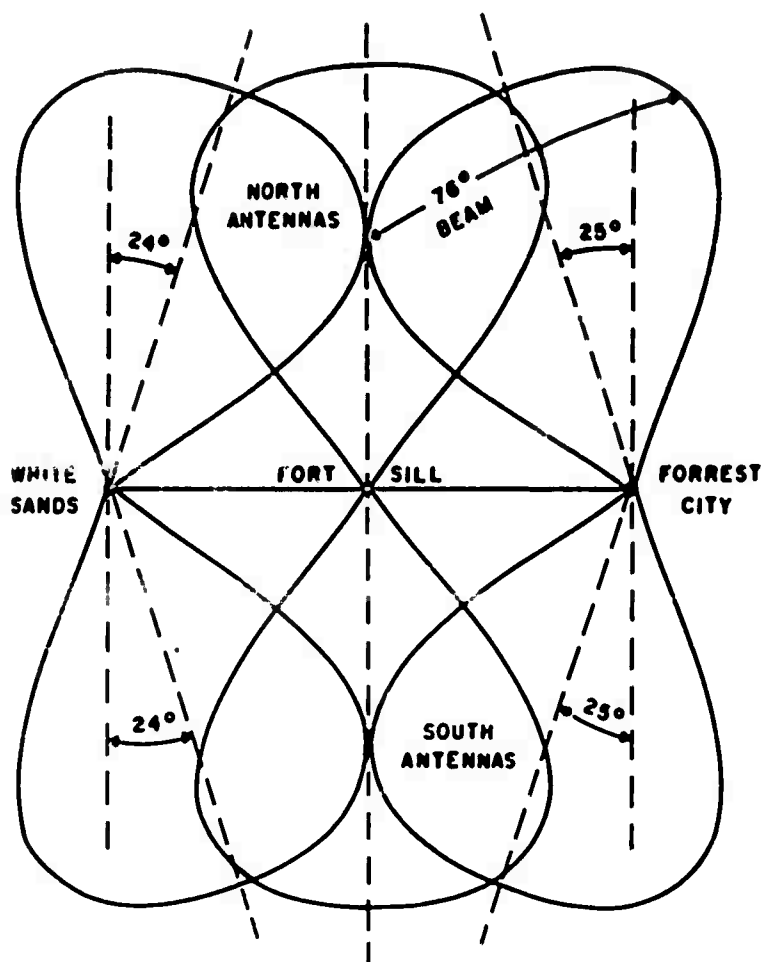
NORTH AND SOUTH ANTENNAS (TOP VIEW)
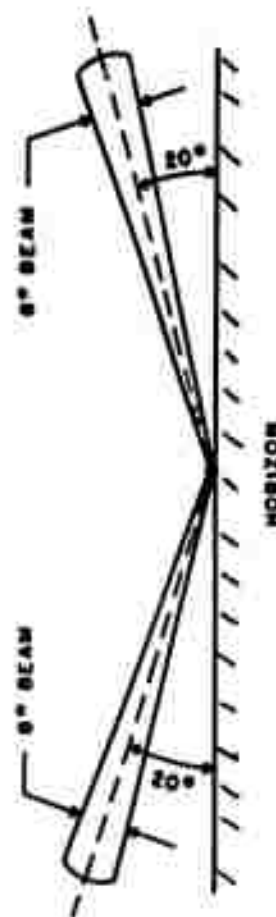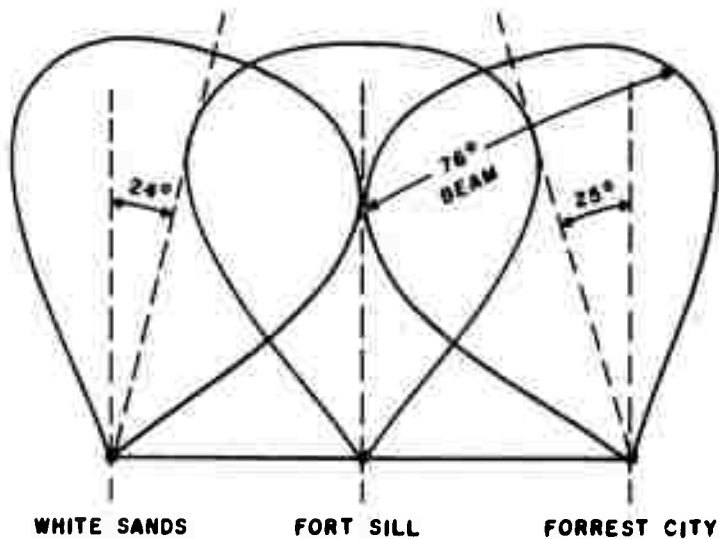
(EDGE VIEW)

CENTER ANTENNAS (SIDE VIEW)
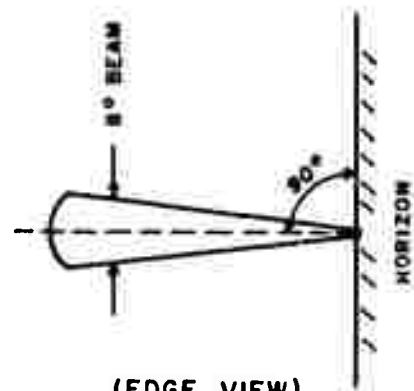
(EDGE VIEW)

FIG. 10 - INITIAL ANTENNA ORIENTATION

66
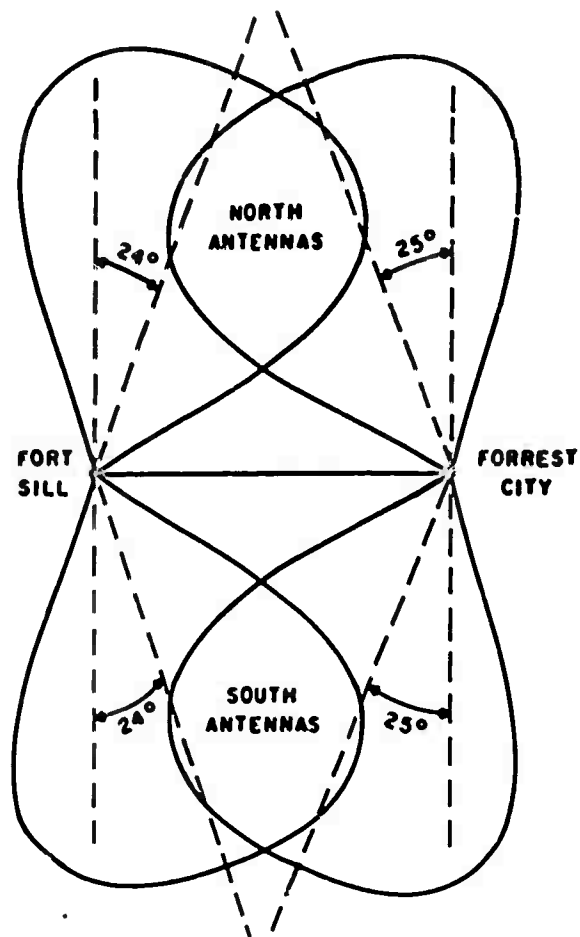
NORTH AND SOUTH ANTENNAS (TOP VIEW)
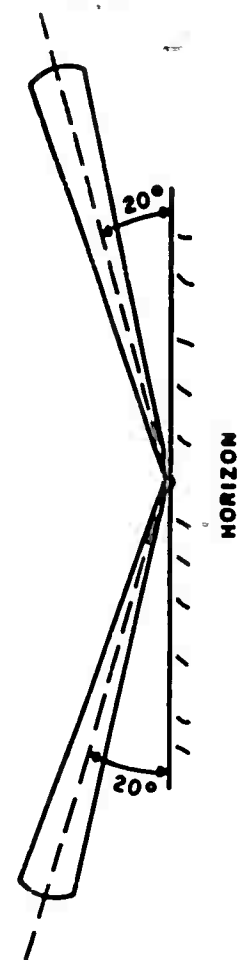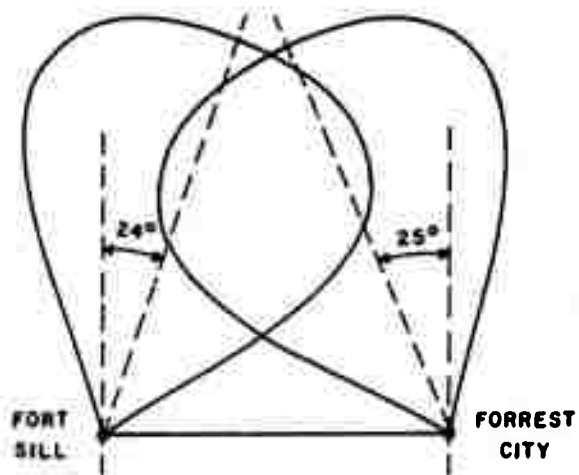
(EDGE VIEW)

CENTER ANTENNAS (SIDE VIEW)
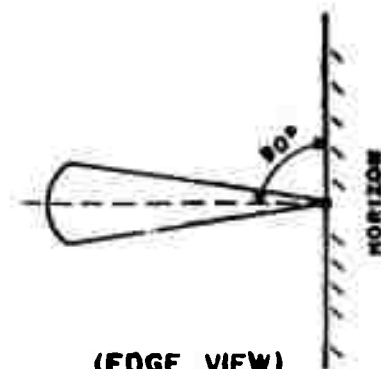
(EDGE VIEW)

FIG. II - ANTENNA ORIENTATION FOLLOWING

DEACTIVATION OF WHITE SANDS STATION

DOPPLER FREQUENCY
KILOCYCLES

SIGNAL STRENGTH
DBM

SATELLITE PASS

SATELLITE PASS

2 SECONDS

TIME

11 SEP 59
0141 Z

ARPA-BRL DOPLOC DOPPLER RECORD OF 58 DELTA
AND 59 EPSILON FORREST CITY, ARKANSAS

58 DELTA REV. 6844
MEASURED 0140:12 Z, PREDICTED 0138 Z
ALTITUDE 407 MILES, 283 MILES EAST FT SILL
CENTER ANTENNA, NORTH-SOUTH PASS

59 EPSILON REV 438
MEASURED 0141:16 Z, PREDICTED 0140 Z
ALTITUDE 150 MILES, 313 MILES EAST FT. SILL
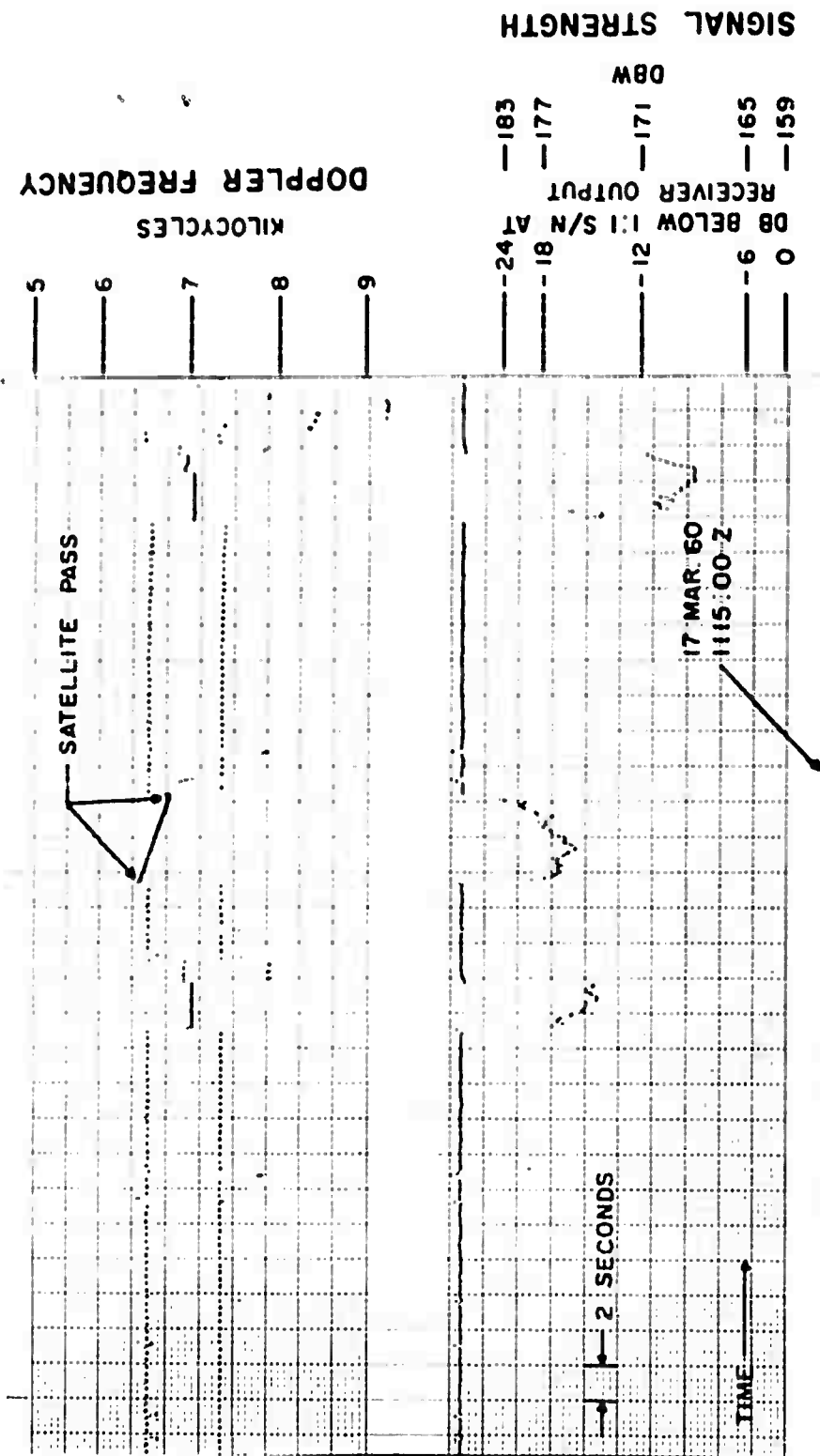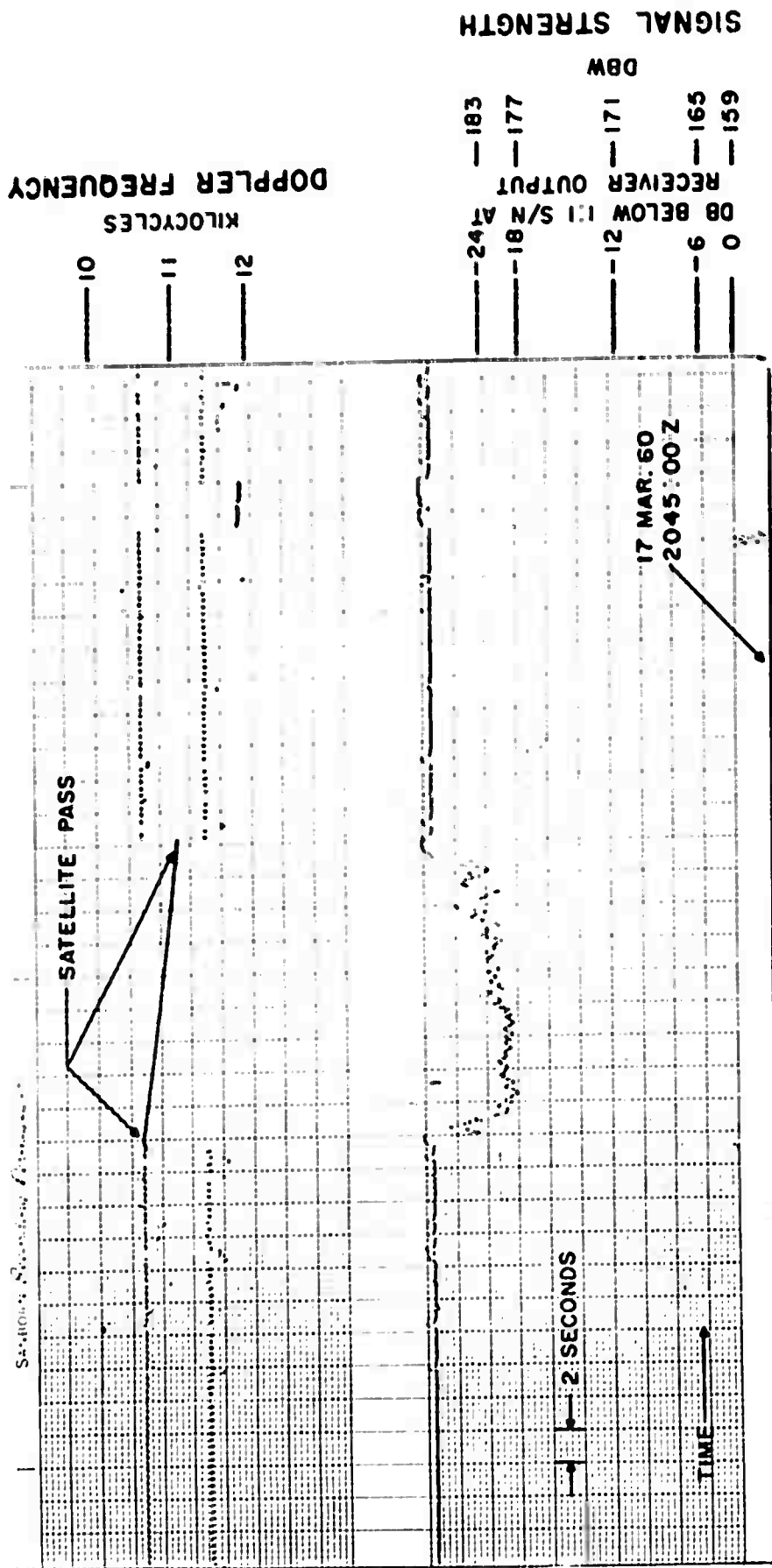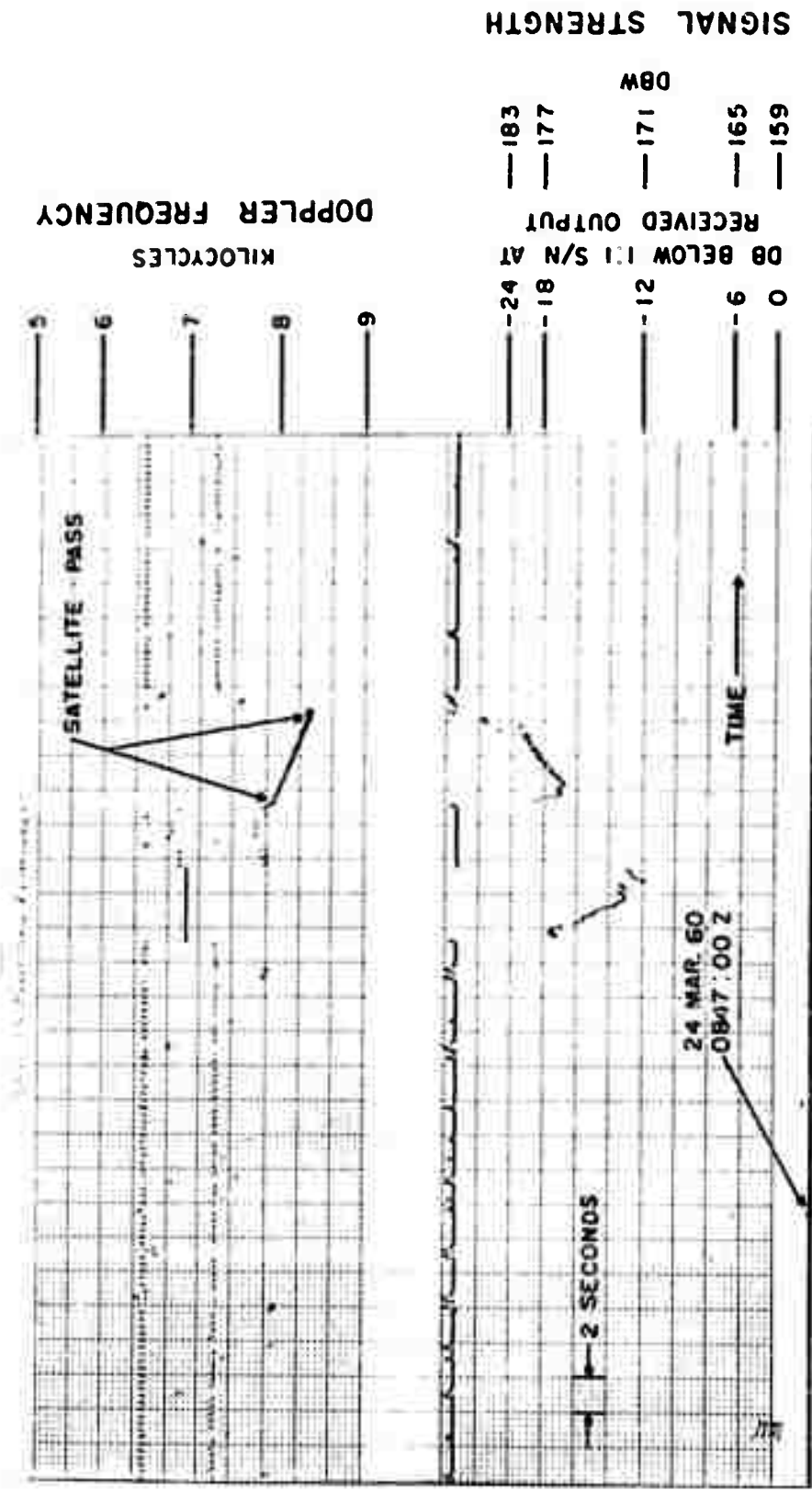CENTER ANTENNA, SOUTH-NORTH PASS

Fig. 12

68

ARPA—BRL DOPLOC DOPPLER RECORD OF 58 DELTA REV. 7049, FORREST CITY, ARKANSAS

MEASURED 2201:56 Z, PREDICTED 2156 Z
ALTITUDE 375 MILES, 214 MILES EAST FT. SILL
CENTER ANTENNA, NORTH—SOUTH PASS

Fig. 13

SIGNAL STRENGTH

DBM

DOPPLER FREQUENCY

KILOCYCLES

SATELLITE PASS

2 SECONDS

TIME

15 OCT 59
1646 Z
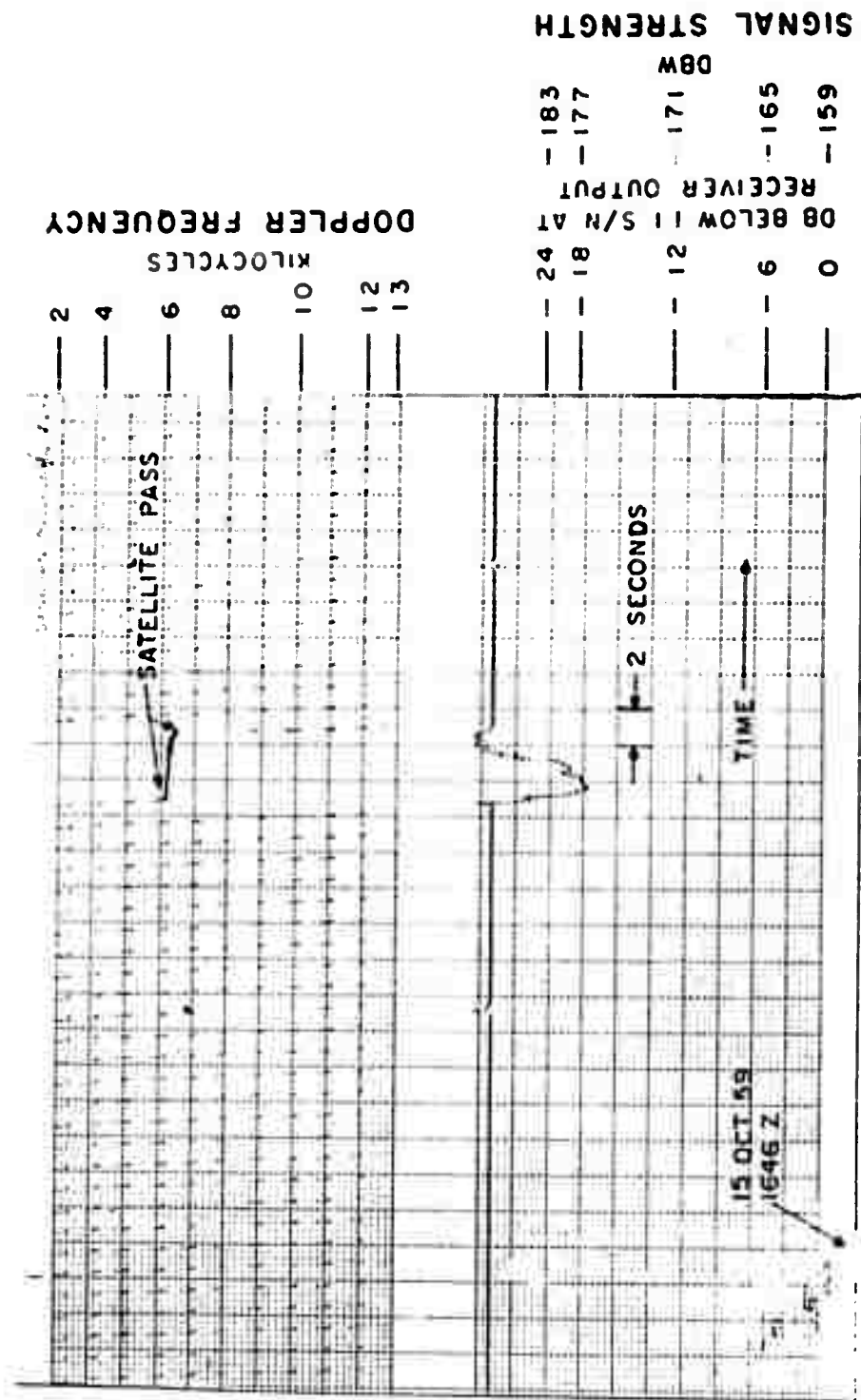
ARPA-BRL DOPLOC DOPPLER RECORD OF
S8 DELTA REV. 7358, FORREST CITY, ARKANSAS
MEASURED 1646:25 Z, PREDICTED 1641 Z
ALTITUDE 369 MILES, 74 MILES WEST FT. SILL
CENTER ANTENNA, NORTH-SOUTH PASS

Fig. 14

DOPPLER FREQUENCY
IN KILOCYCLES

SIGNAL STRENGTH
DBW

SIGNAL STRENGTH
IN DECIBELS BELOW
0.07 MICROVOLTS

SATELLITE PASS

TIME

2 SECONDS

22 DEC 59
21:36:00 Z
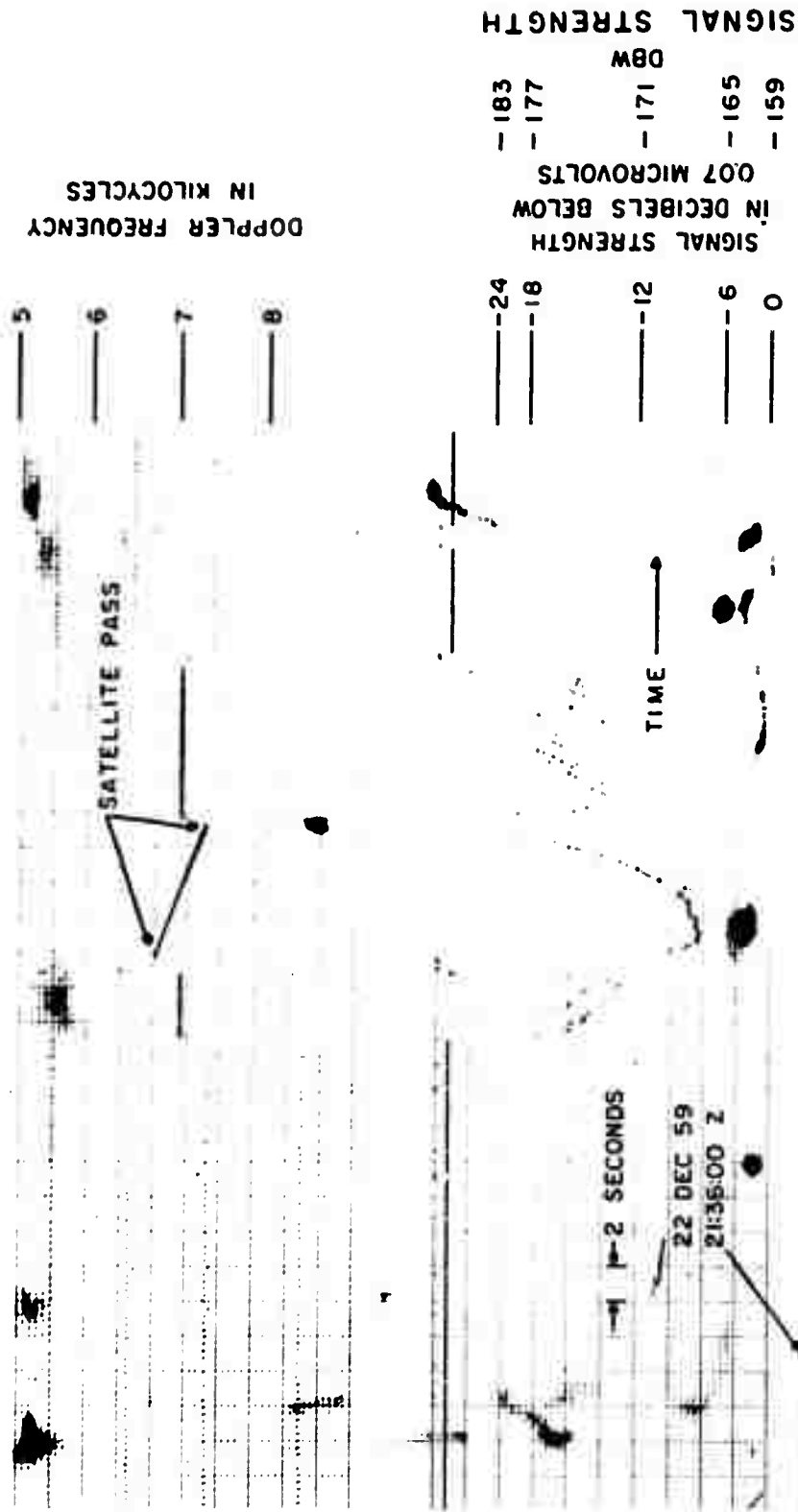
ARPA - BRL DOPLOC DOPPLER RECORD OF
58 DELTA REV 8386 FORREST CITY, ARKANSAS
MEASURED 21:36:23 Z, PREDICTED 21:32 Z
ALTITUDE 172 MILES, 176 MILES EAST FT. SILL
CENTER ANTENNA, N-S PASS

Fig. 15

71

DOPPLER FREQUENCY
IN KILOCYCLES

SIGNAL STRENGTH
IN DECIBELS BELOW
0.07 MICROVOLTS

SATELLITE PASS

TIME

2 SECONDS

8 JAN. 60
1647:00 Z

1648:00
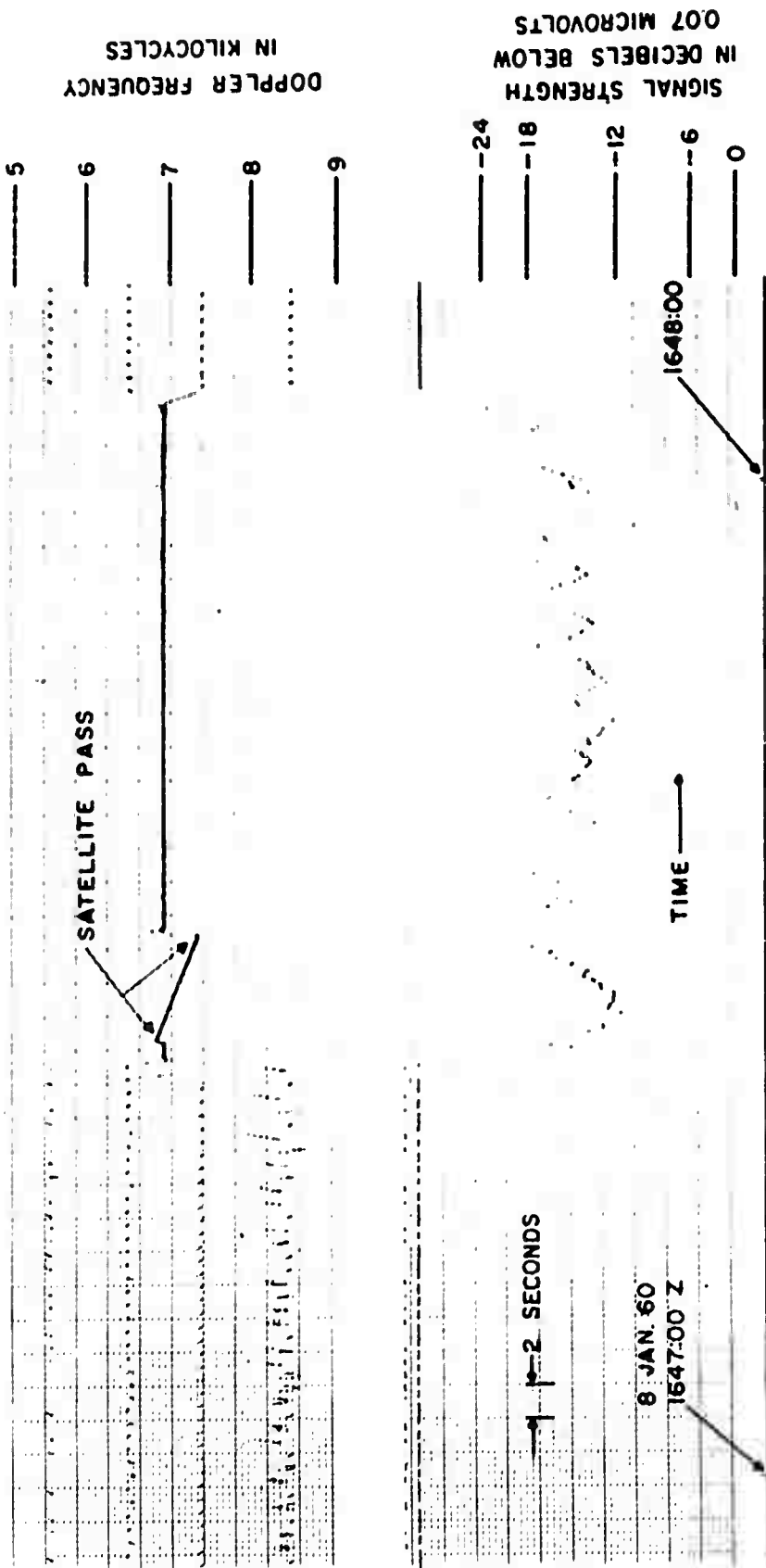
ARPA—BRL DOPLOC DOPPLER RECORD OF
58 DELTA REV. 8643, FORREST CITY, ARKANSAS
MEASURED 1647:25 Z, PREDICTED 1647 Z
ALTITUDE 156 MILES, 139 MILES EAST FT. SILL
CENTER ANTENNA, NORTH—SOUTH PASS

Fig. 16

72

SIGNAL STRENGTH
DBW

DOPPLER FREQUENCY
IN KILOCYCLES

SIGNAL STRENGTH
IN DECIBELS BELOW
0.07 MICROVOLTS

SATELLITE PASS

065200

2 SECONDS

11 JAN 6U
065100 Z
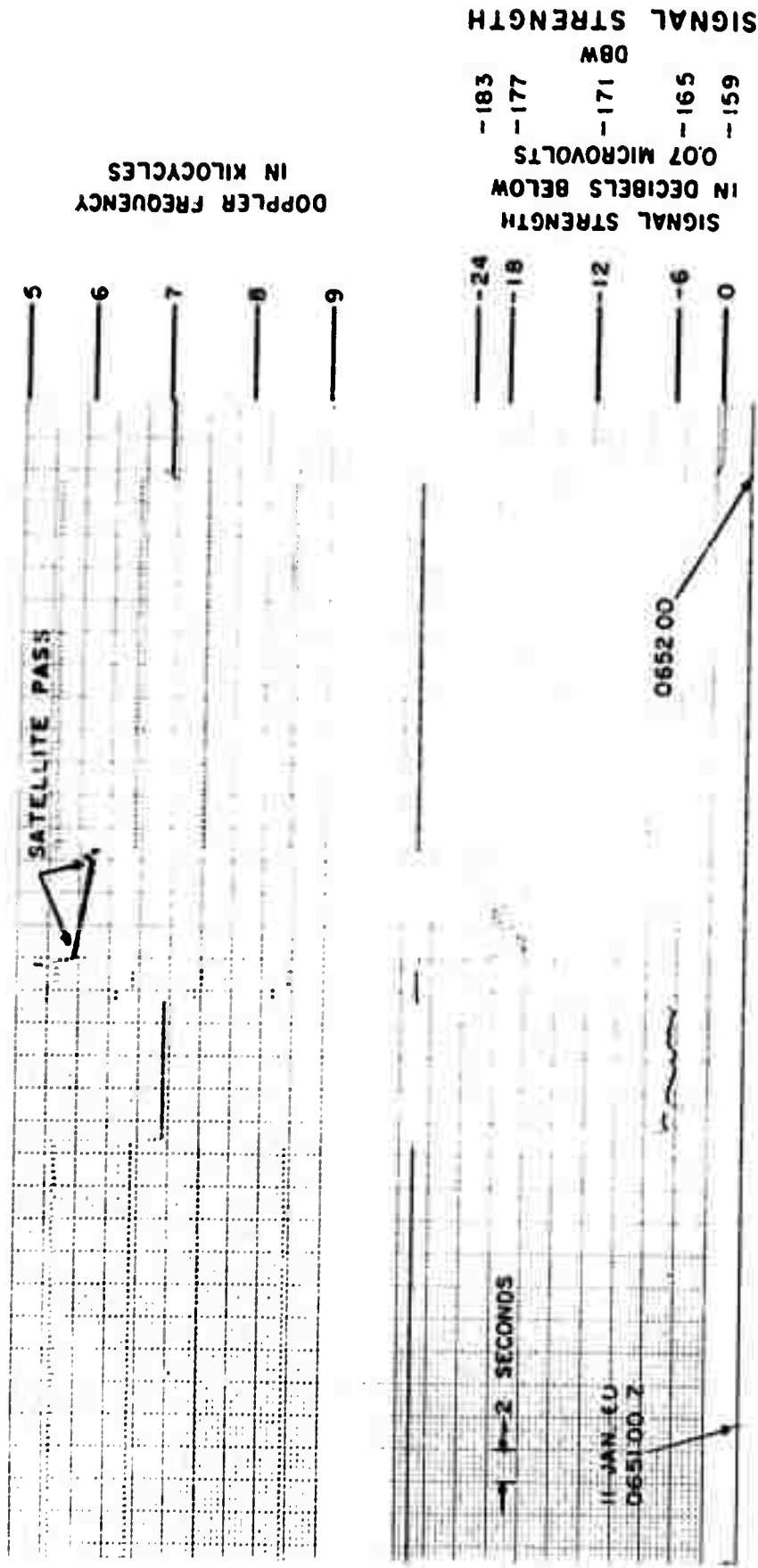
ARPA – BRL DOPLOC DOPPLER RECORD OF
58 DELTA REV. 8683, FORREST CITY, ARKANSAS
MEASURED 0651:30 Z, PREDICTED 0651 Z
ALTITUDE 413 MILES, OVERHEAD FT. SILL
CENTER ANTENNA, SOUTH–NORTH PASS

Fig. 17

73

DOPPLER FREQUENCY
IN KILOCYCLES

SIGNAL STRENGTH
IN DECIBELS BELOW
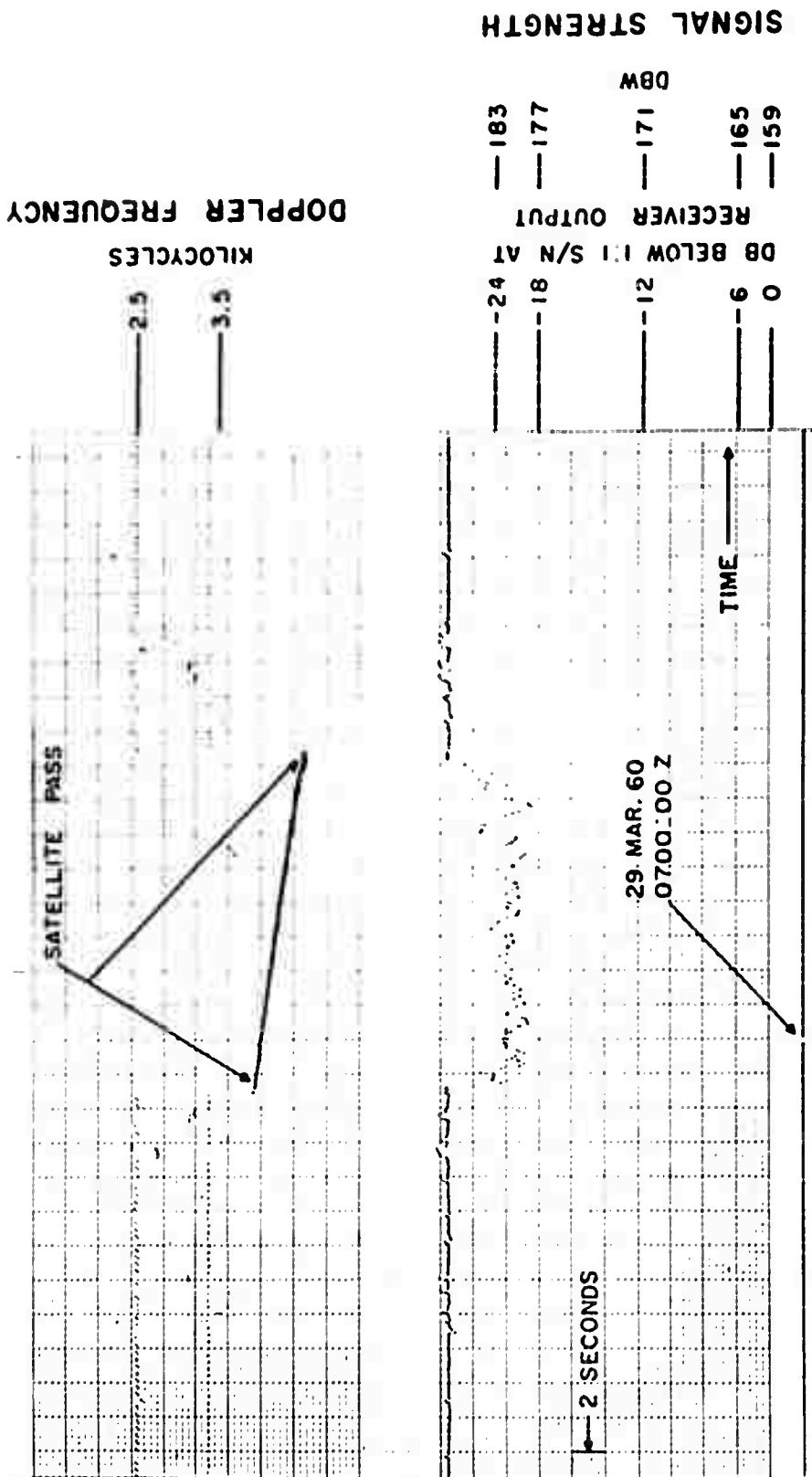0.07 MICROVOLTS

SATELLITE PASS

2 SECONDS

13 JAN. 60
1530 Z

TIME
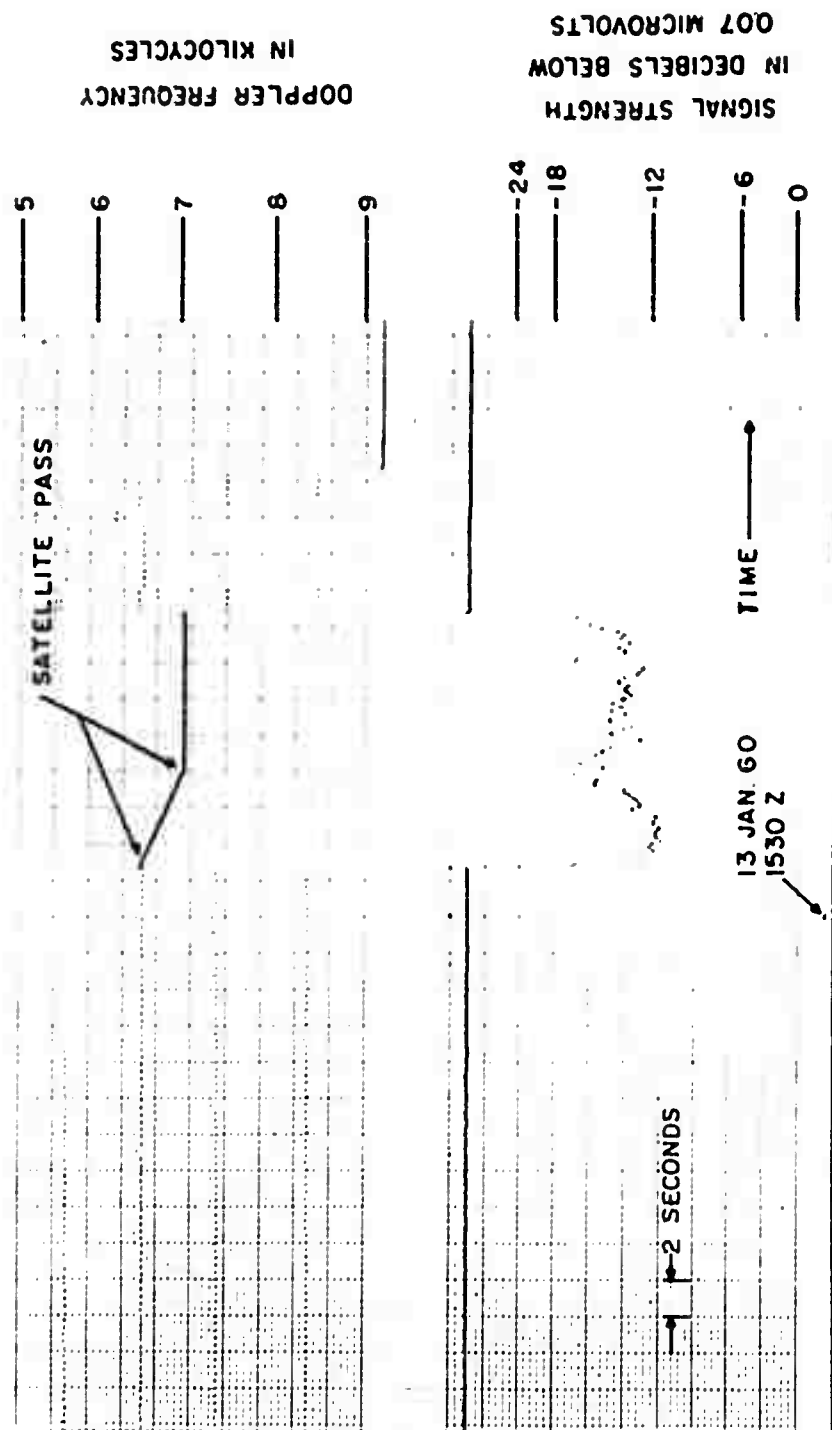
ARPA—BRL DOPLOC DOPPLER RECORD OF
58 DELTA REV. 8719, FORREST CITY, ARKANSAS
MEASURED 1530:03 Z, PREDICTED 1528 Z
ALTITUDE 186 MILES, 50 MILES EAST FT. SILL
CENTER ANTENNA, NORTH—SOUTH PASS

Fig. 18

74

DOPPLER FREQUENCY
IN KILOCYCLES

SIGNAL STRENGTH
IN DECIBELS BELOW
0.07 MICROVOLTS

SATELLITE PASS

TIME

14 JAN. 60
1454 Z

2 SECONDS
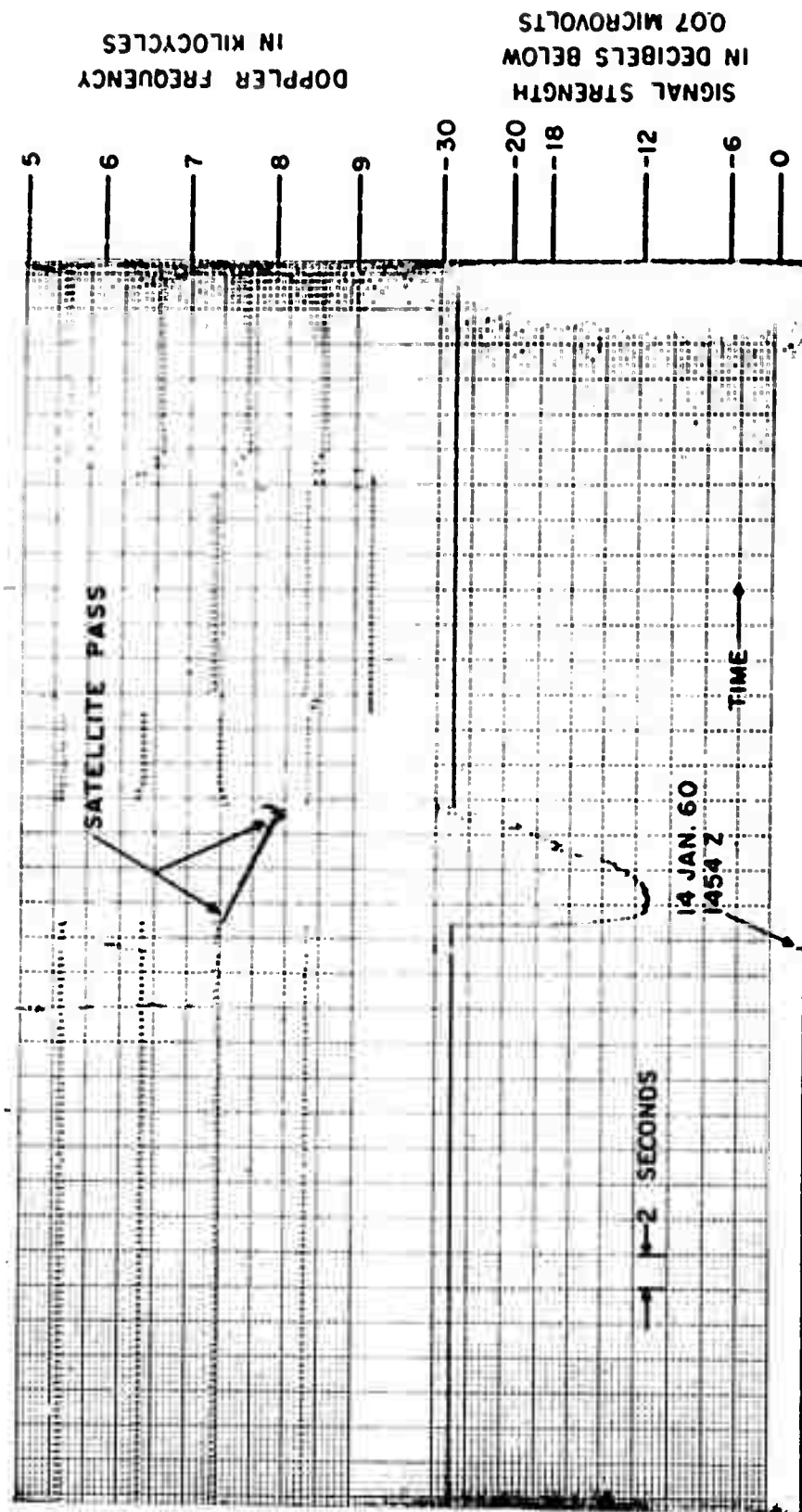
ARPA – BRL DOPLOC DOPPLER RECORD OF
58 DELTA REV. 8734, FORREST CITY, ARKANSAS
MEASURED 1454:02 Z, PREDICTED 1452 Z
ALTITUDE 186 MILES, 326 EAST FT. SILL
CENTER ANTENNA, NORTH–SOUTH PASS

Fig. 19

75

DOPPLER FREQUENCY
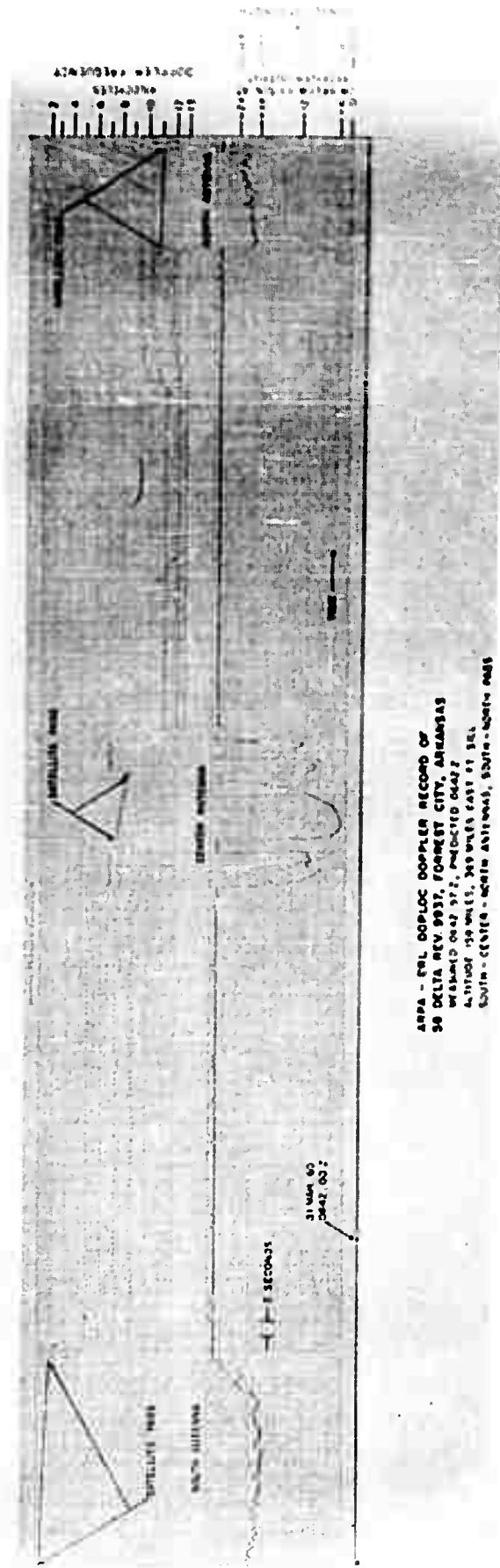IN KILOCYCLES

SIGNAL STRENGTH
IN DECIBELS BELOW
0.07 MICROVOLTS
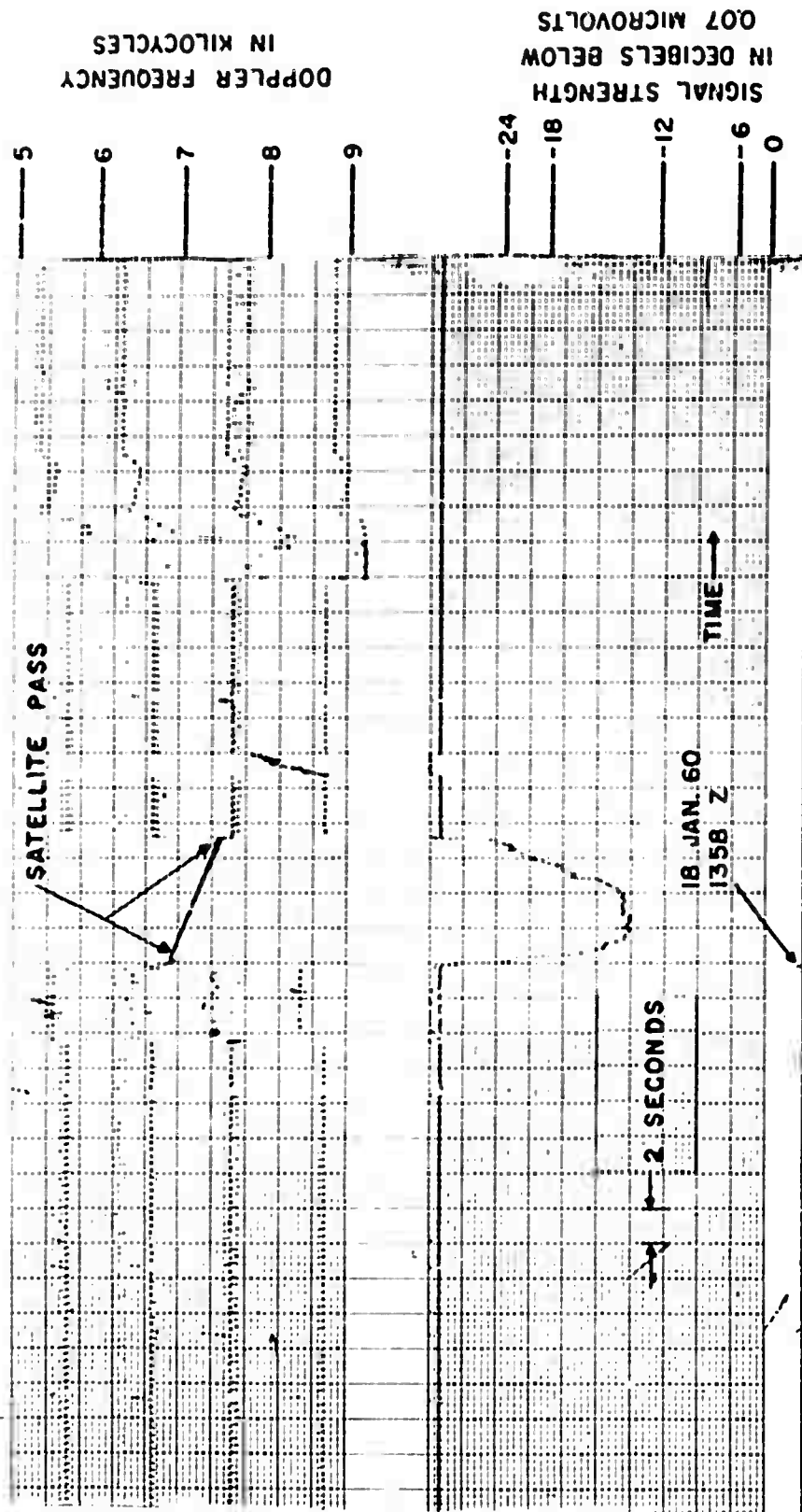
ARPA–BRL DOPLOC DOPPLER RECORD OF
58 DELTA REV. 8795, FORREST CITY, ARKANSAS
MEASURED 1358:01 Z, PREDICTED 1356 Z
ALTITUDE 146 MILES, 158 MILES EAST FT. SILL
CENTER ANTENNA, NORTH–SOUTH PASS

Fig. 20

SATELLITE PASS

TIME

18 JAN. 60
1358 Z

2 SECONDS

DOPPLER FREQUENCY IN KILOCYCLES

SIGNAL STRENGTH IN DECIBELS BELOW 0.07 MICROVOLTS

SATELLITE PASS

TIME
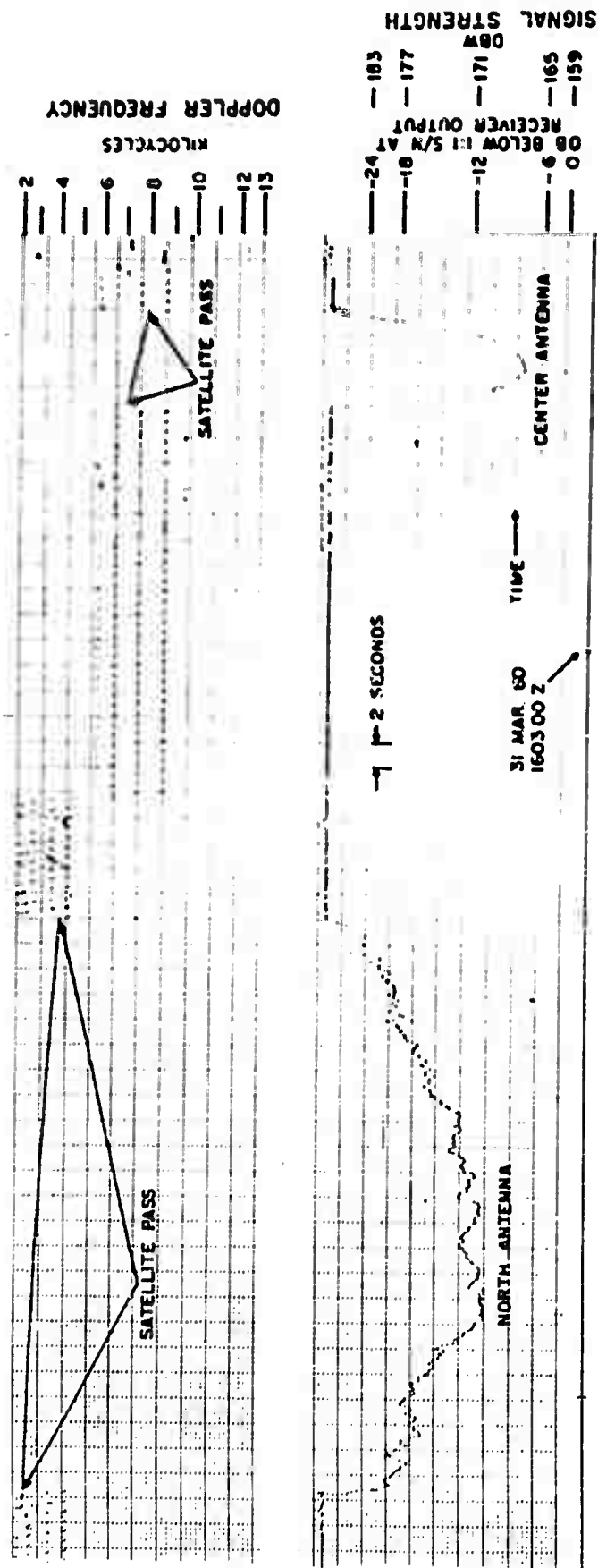
1 FEB. 60 1011 Z

2 SECONDS
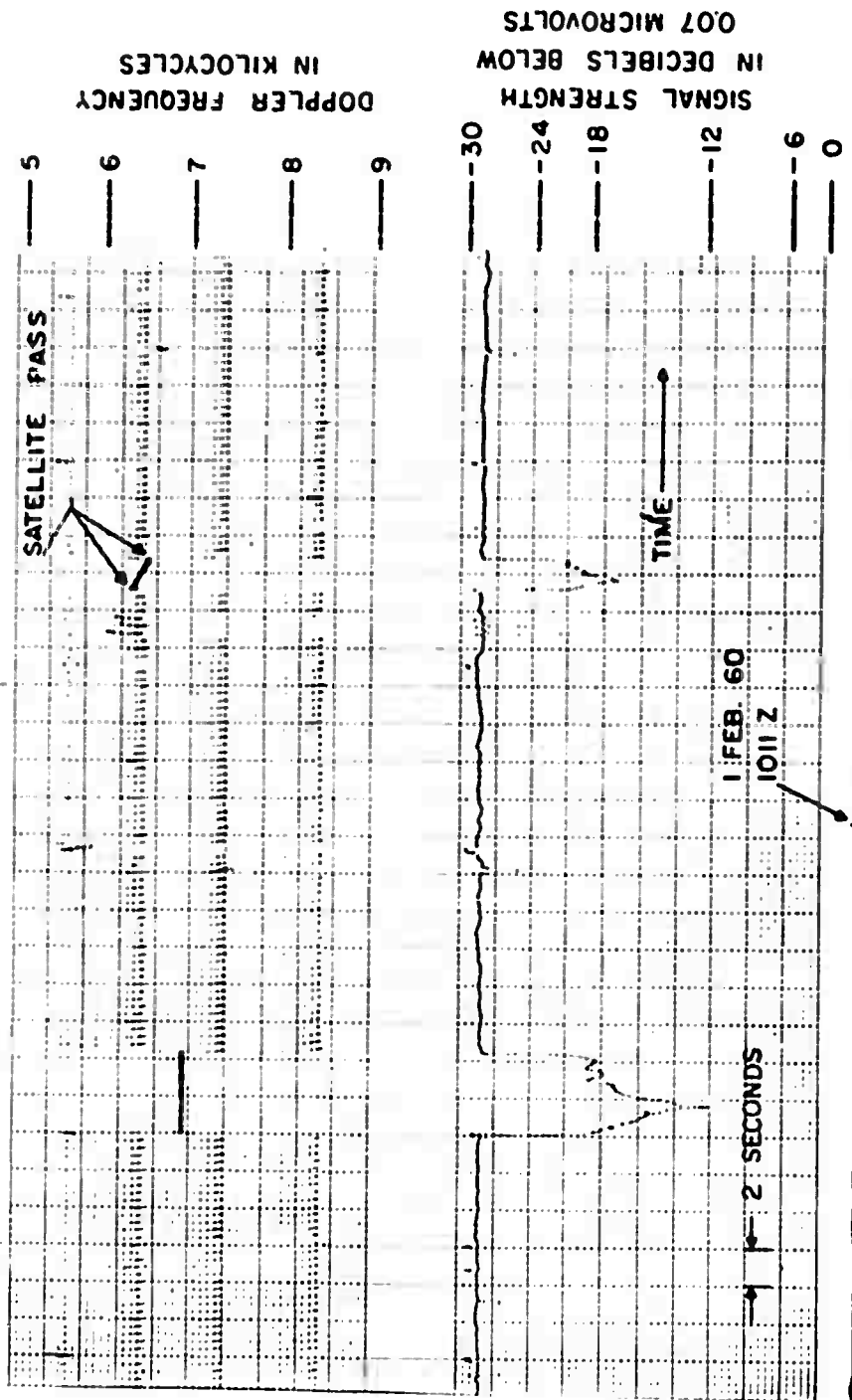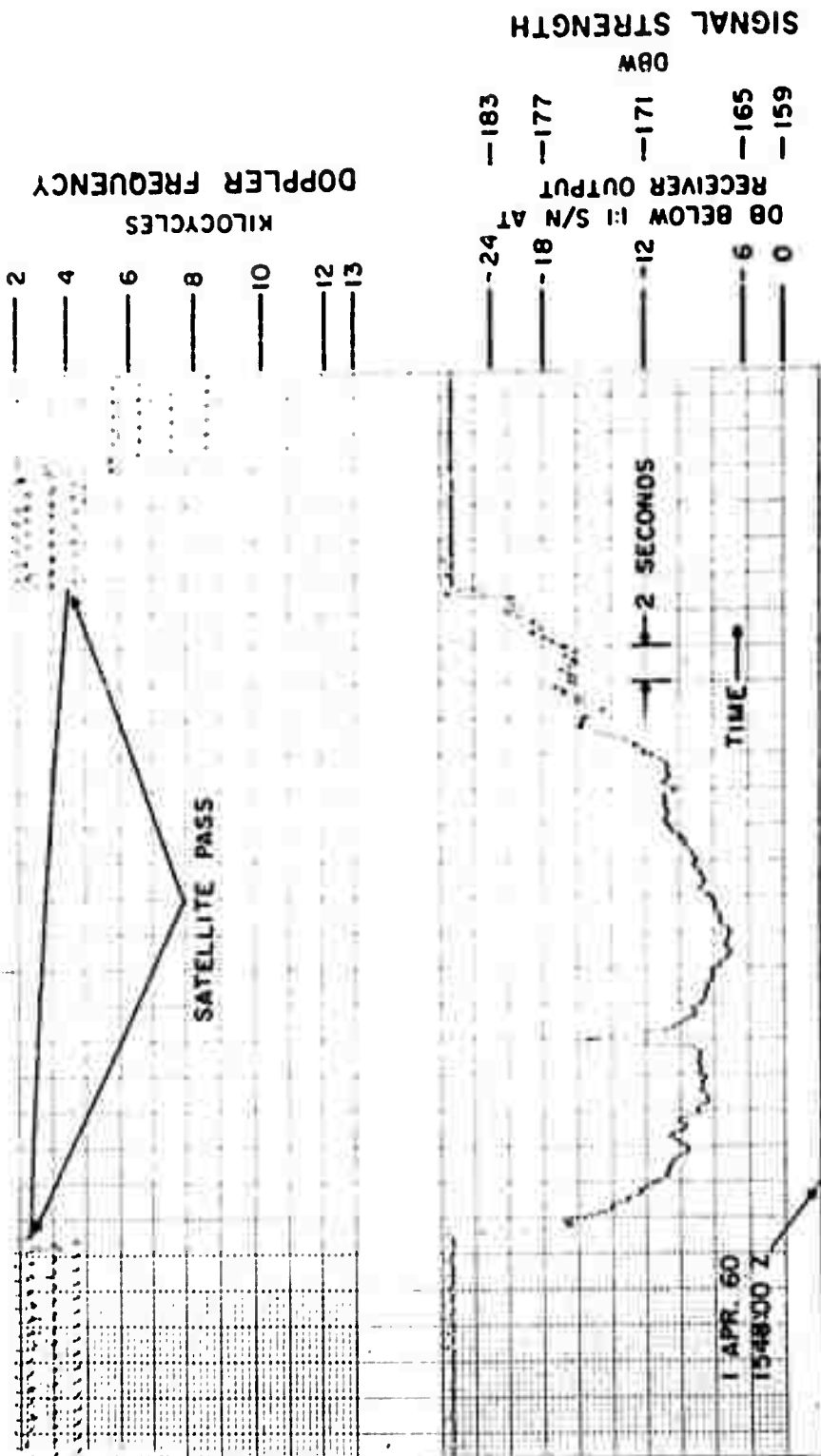
ARPA — BRL DOPLOC DOPPLER RECORD OF
58 DELTA REV. 9009, FORREST CITY, ARKANSAS
MEASURED 1011:12 Z, PREDICTED 1009 Z
ALTITUDE 134 MILES, 46 MILES WEST FT. SILL
CENTER ANTENNA, NORTH—SOUTH PASS

Fig. 21

77

DOPPLER FREQUENCY IN KILOCYCLES

SIGNAL STRENGTH IN DECIBELS BELOW 0.07 MICROVOLTS

SATELLITE PASS

TIME

2 SECONDS

11 FEB. 60
2121 Z
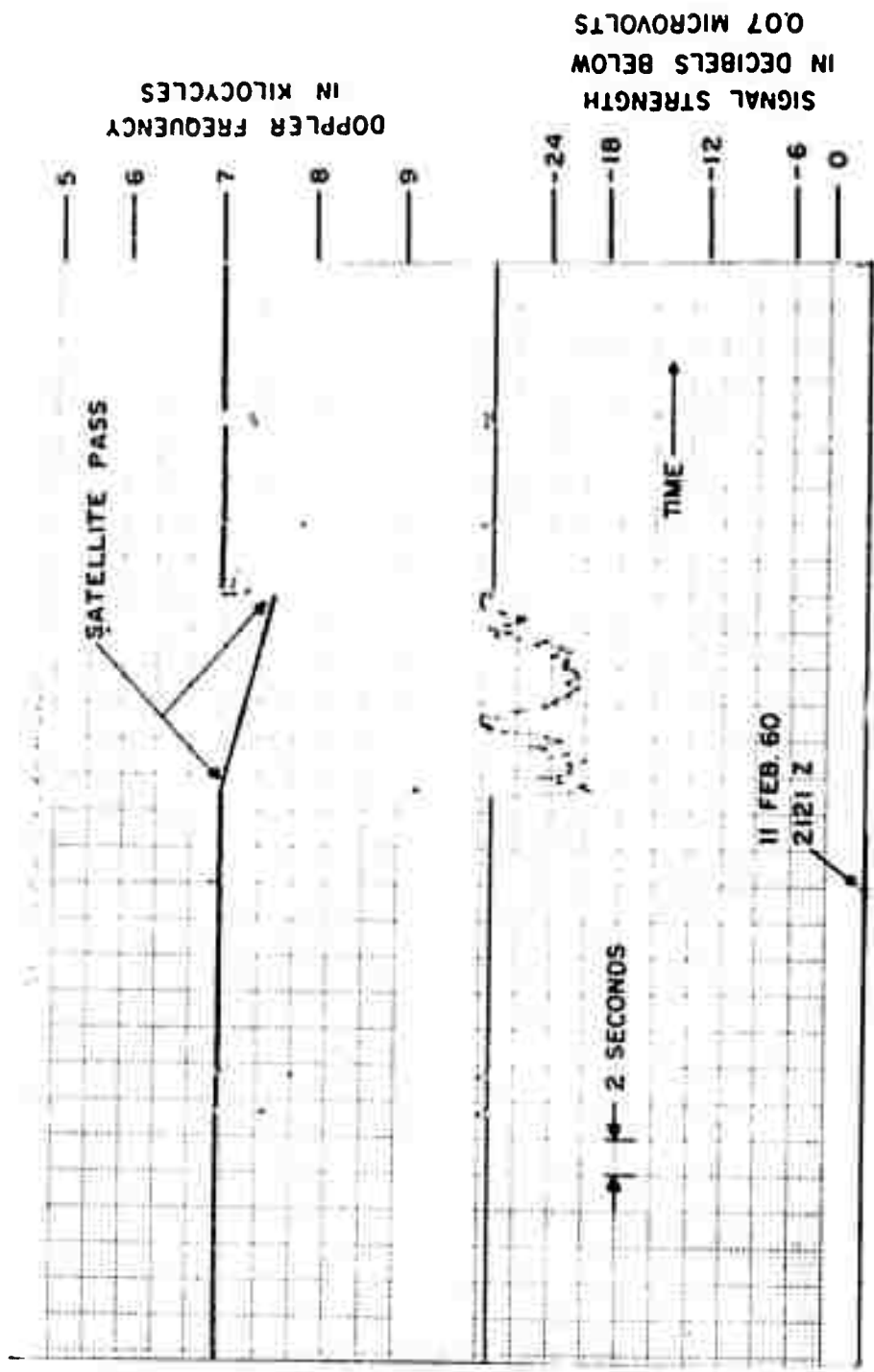
ARPA-BRL DOPLOC DOPPLER RECORD OF
58 DELTA REV. 9172 FORREST CITY, ARKANSAS
MEASURED 2121:06 Z, PREDICTED 2119 Z
ALTITUDE 315 MILES, 300 MILES EAST FT. SILL
CENTER ANTENNA, SOUTH—NORTH PASS

Fig. 22

DOPPLER FREQUENCY
IN KILOCYCLES

SIGNAL STRENGTH
IN DECIBELS BELOW
0.07 MICROVOLTS
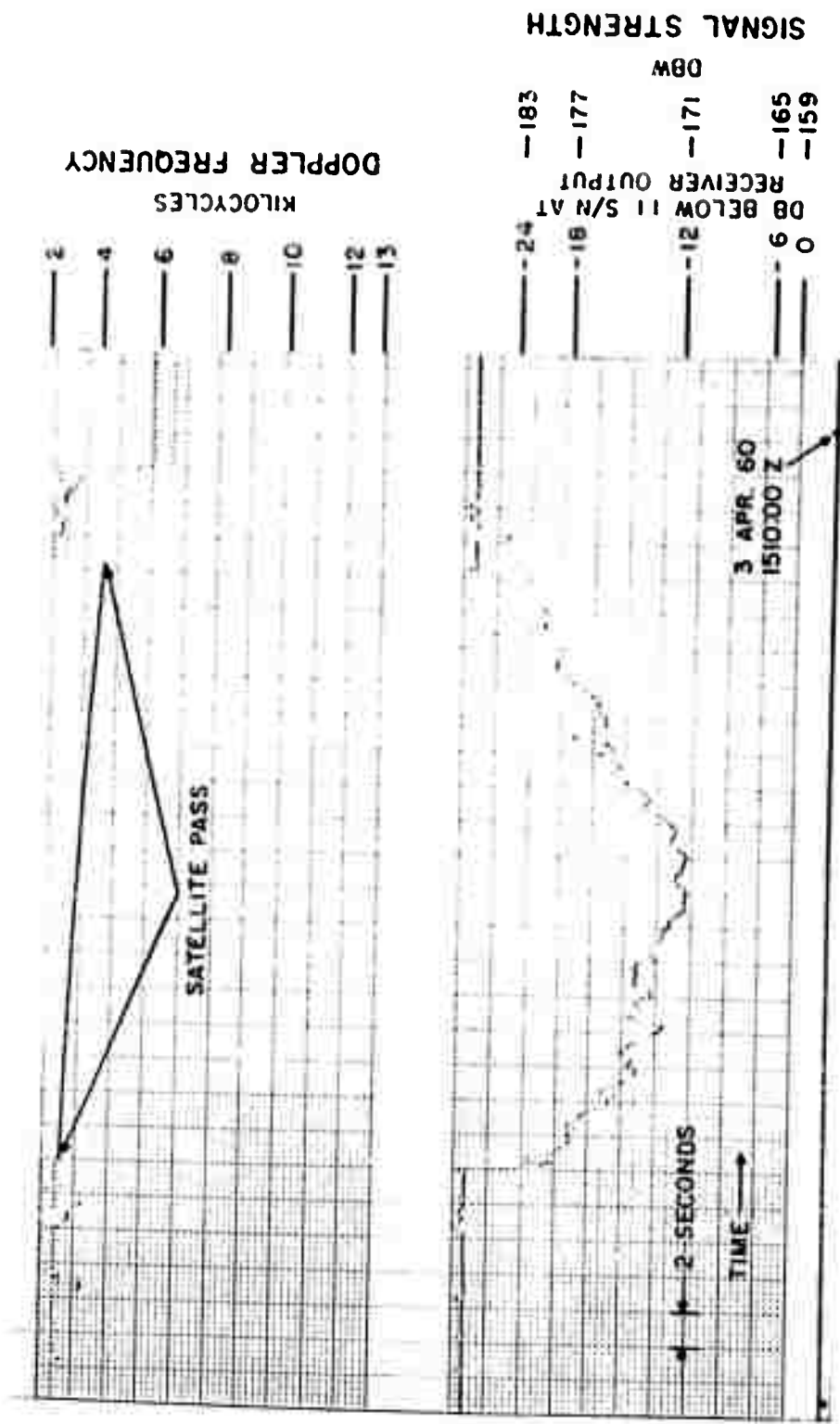
SATELLITE PASS

TIME

2 SECONDS

17 FEB. 60
0524 Z
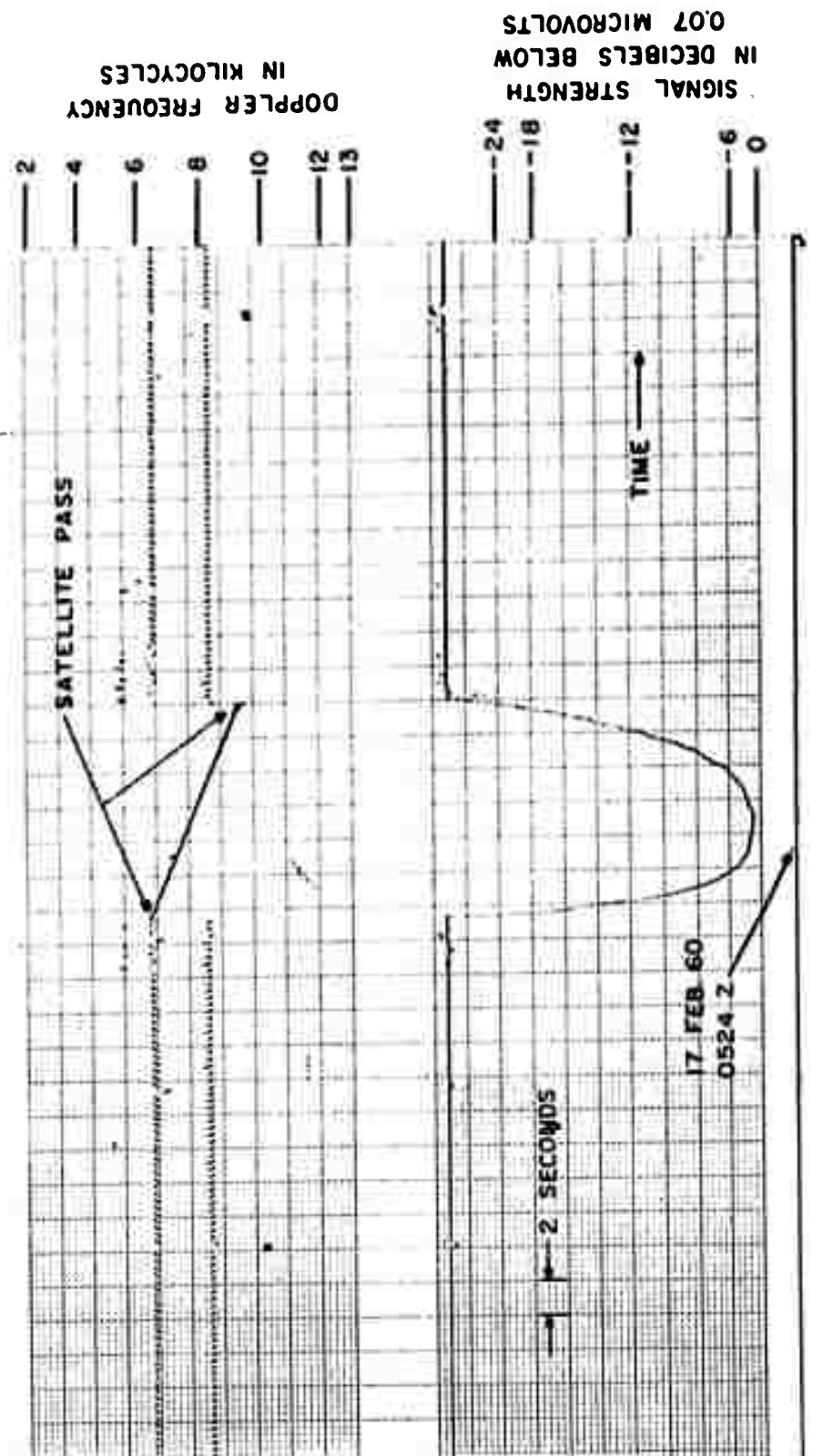
ARPA—BRL DOPLOC DOPPLER RECORD OF
58 DELTA REV. 9255 FORREST CITY, ARKANSAS
MEASURED 0523:57 Z, PREDICTED 0521 Z
ALTITUDE 128 MILES, 120 MILES EAST FT. SILL
CENTER ANTENNA . NORTH—SOUTH PASS

Fig. 23

79

DOPPLER FREQUENCY
IN KILOCYCLES

SIGNAL STRENGTH
IN DECIBELS BELOW
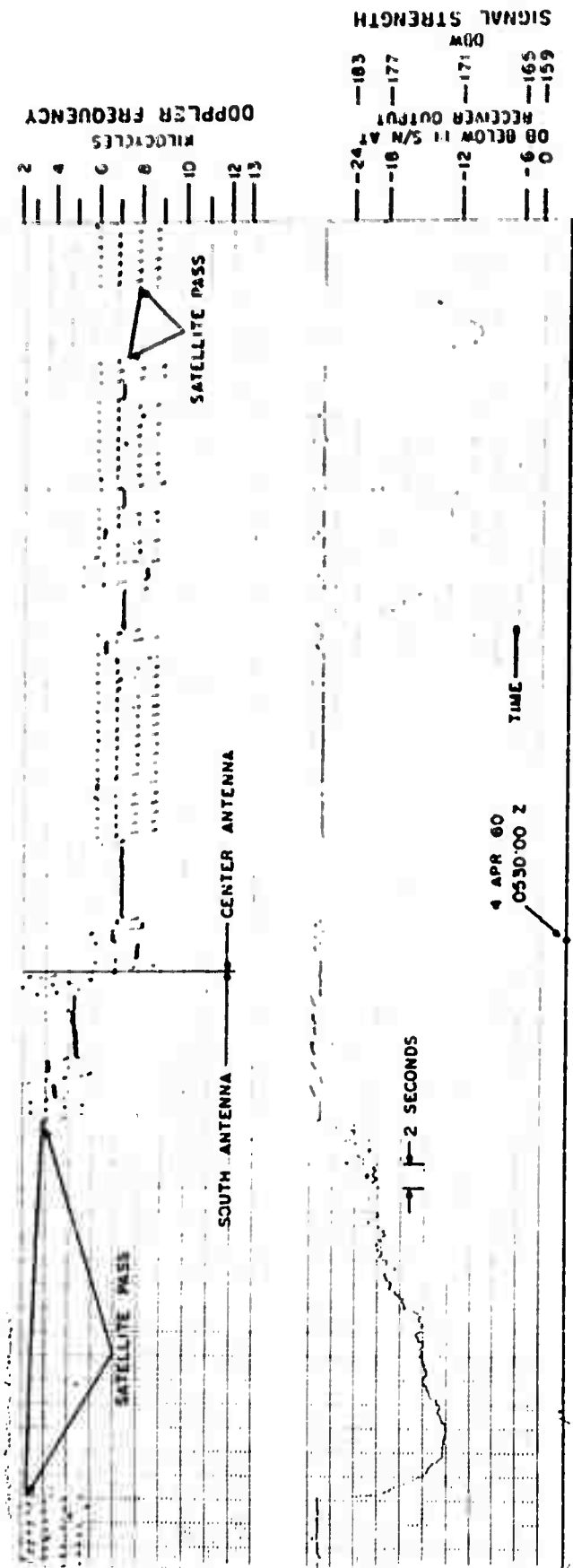.007 MICROVOLTS

SATELLITE PASS

2 SECONDS

19-FEB-60
0459 Z

TIME
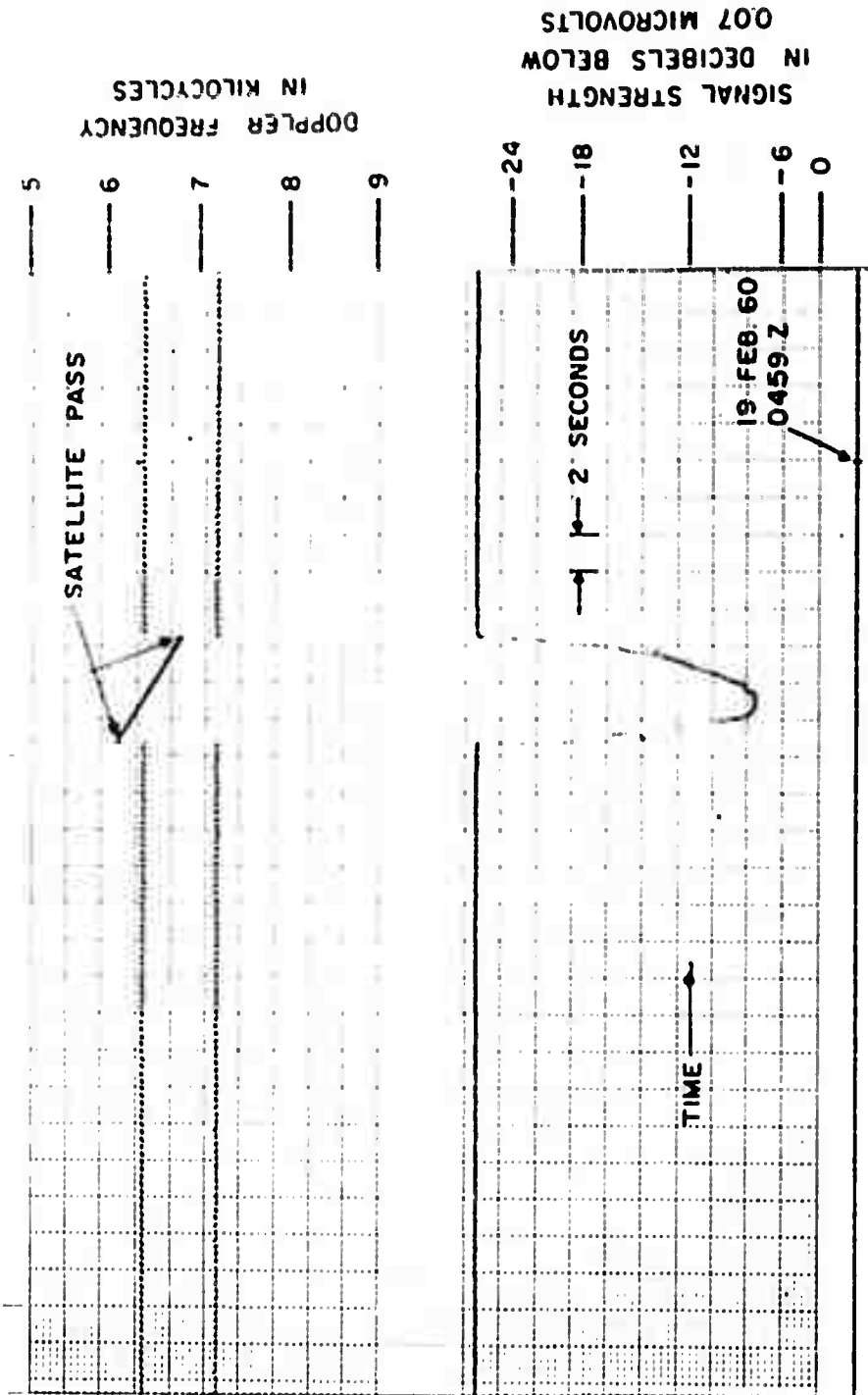
ARPA — BRL DOPLOC DOPPLER RECORD OF
58 DELTA REV. 9286 FORREST CITY, ARKANSAS
MEASURED 0458·45 Z, PREDICTED 0457 Z
ALTITUDE 123 MILES, 39 MILES WEST FT. SILL
CENTER ANTENNA, NORTH—SOUTH PASS

Fig. 24
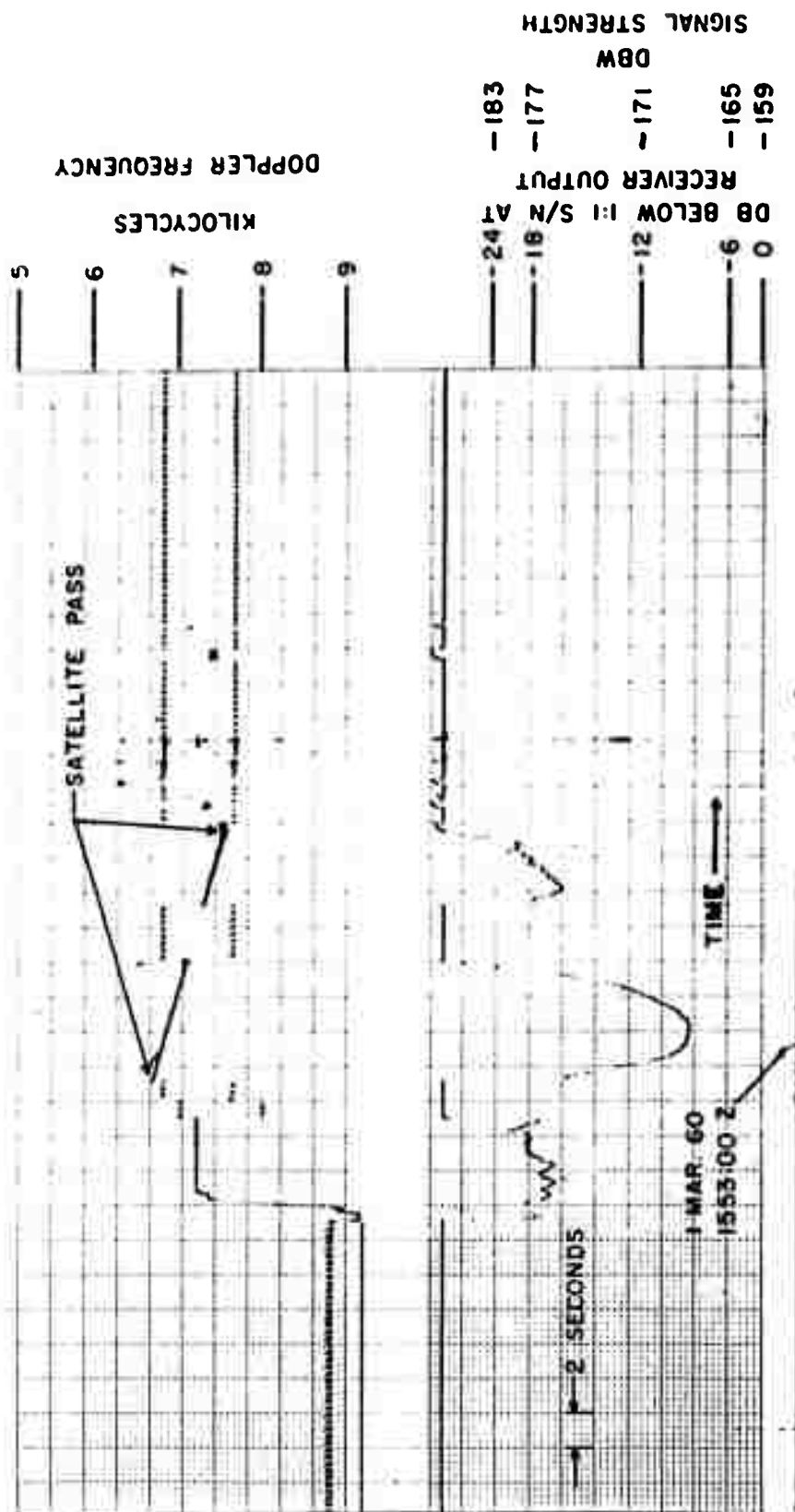
ARPA — BRL DOPLOC DOPPLER RECORD OF
58 DELTA REV. 9466 , FORREST CITY, ARKANSAS
MEASURED 1552:58 Z , PREDICTED 1548 Z
ALTITUDE 275 MILES , 289 MILES EAST FT. SILL
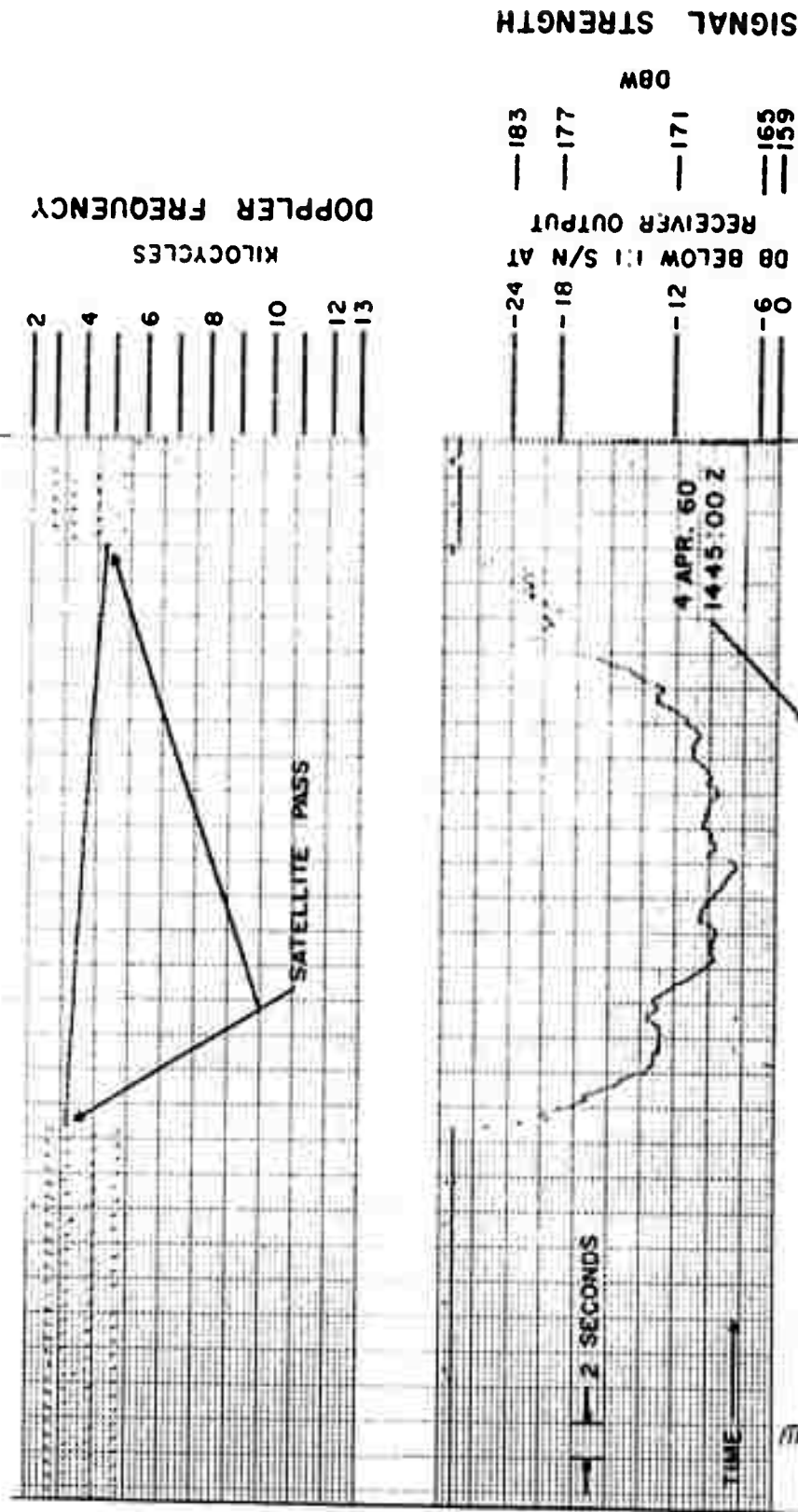CENTER ANTENNA, SOUTH — NORTH PASS

FIG. 25
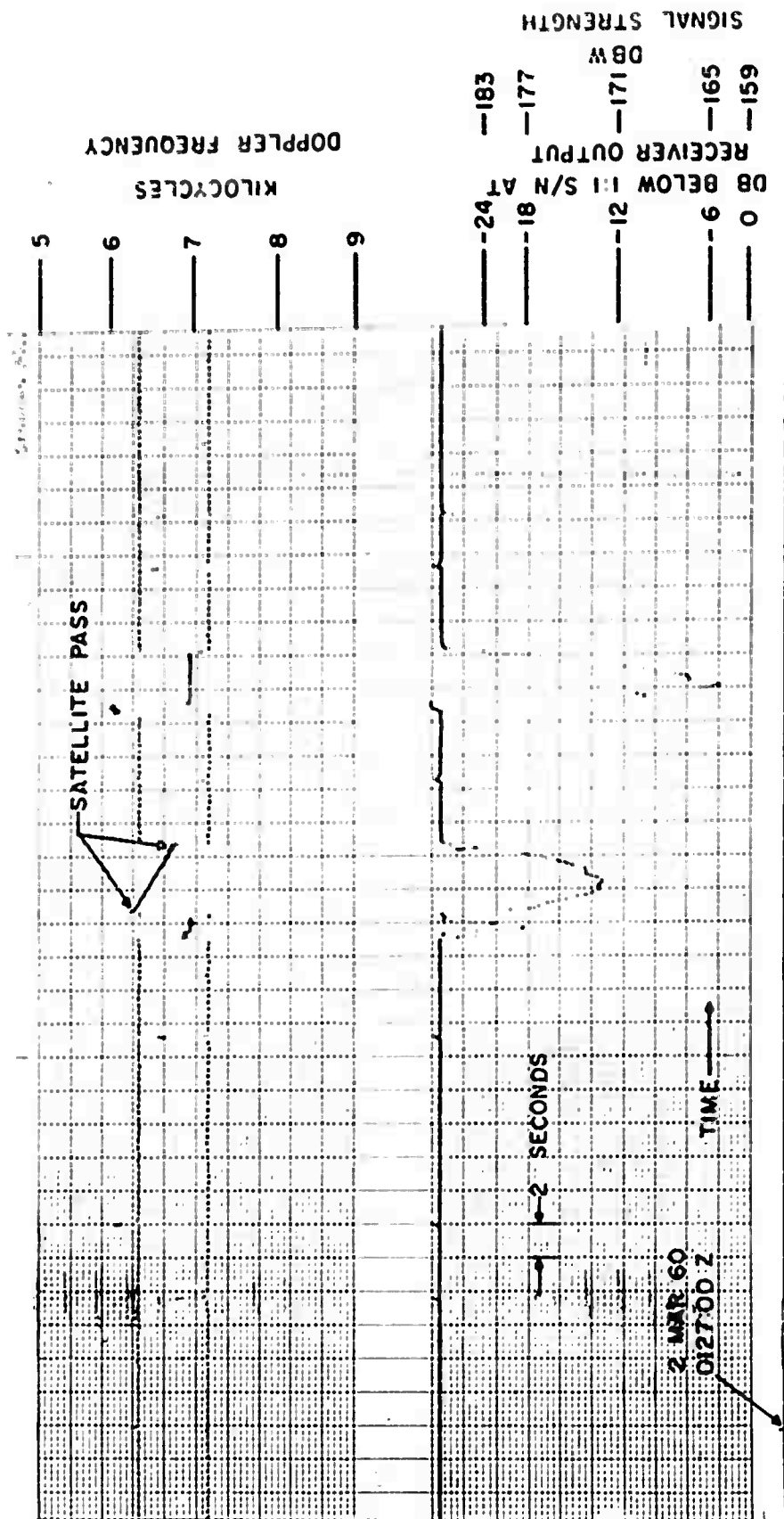
ARPA – BRL DOPLOC DOPPLER RECORD OF
58 DELTA REV. 9472, FORREST CITY, ARKANSAS
MEASURED 0127:31 Z, PREDICTED 0128 Z
ALTITUDE 130 MILES, 80 MILES WEST FT. SILL
CENTER ANTENNA, NORTH-SOUTH PASS

Fig. 26

SIGNAL STRENGTH

DOPPLER FREQUENCY
KILOCYCLES

SATELLITE PASS

2 SECONDS

TIME

4 MAR. 60
0042:00 Z
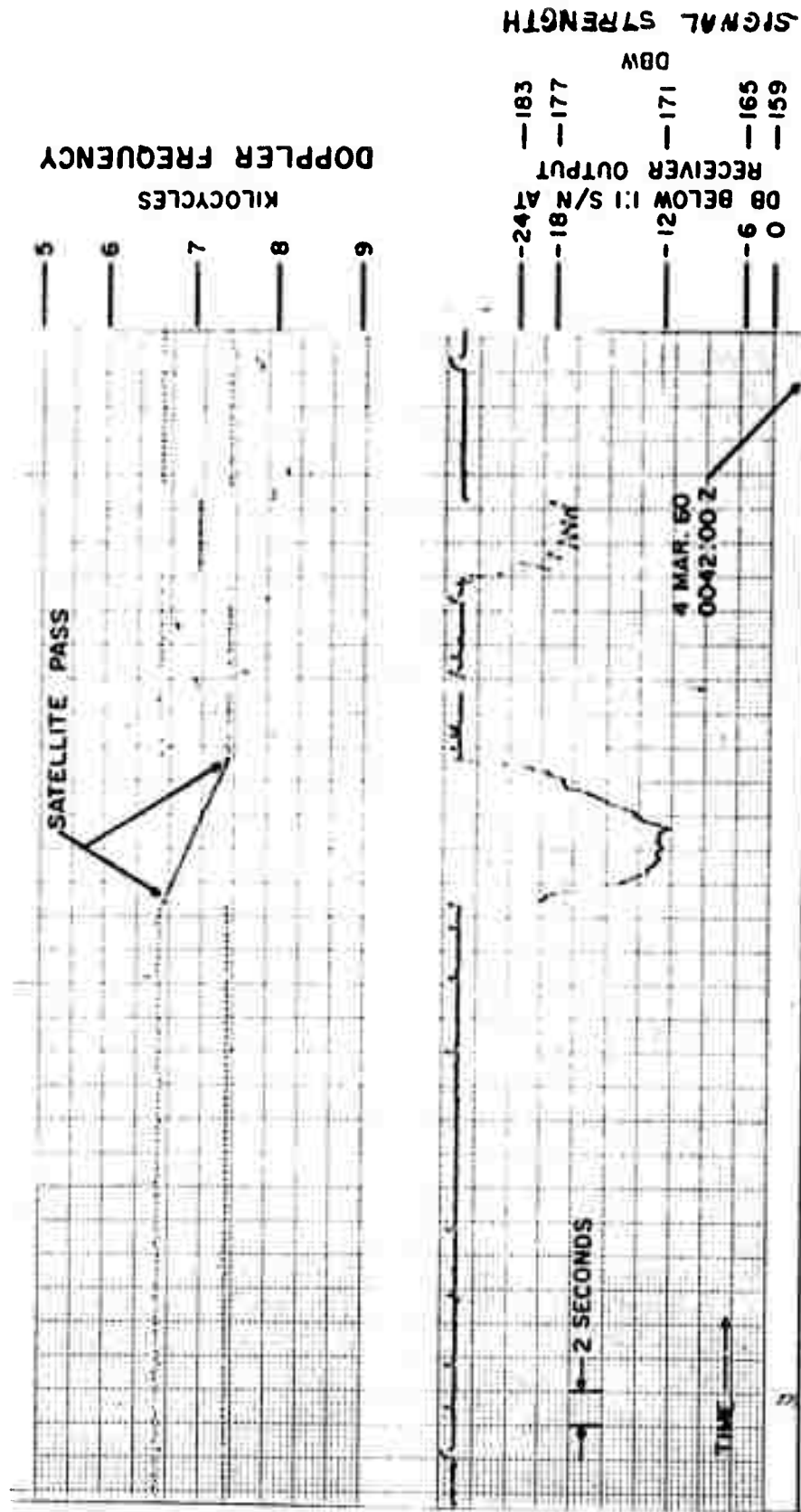
ARPA – BRL DOPLOC DOPPLER RECORD OF
58 DELTA REV 9503, FORREST CITY, ARKANSAS

MEASURED 0014:30 Z, PREDICTED 0043 Z
ALTITUDE 130 MILES, 56 MILES EAST FT. SILL
CENTER ANTENNA, NORTH – SOUTH PASS

Fig. 27

83
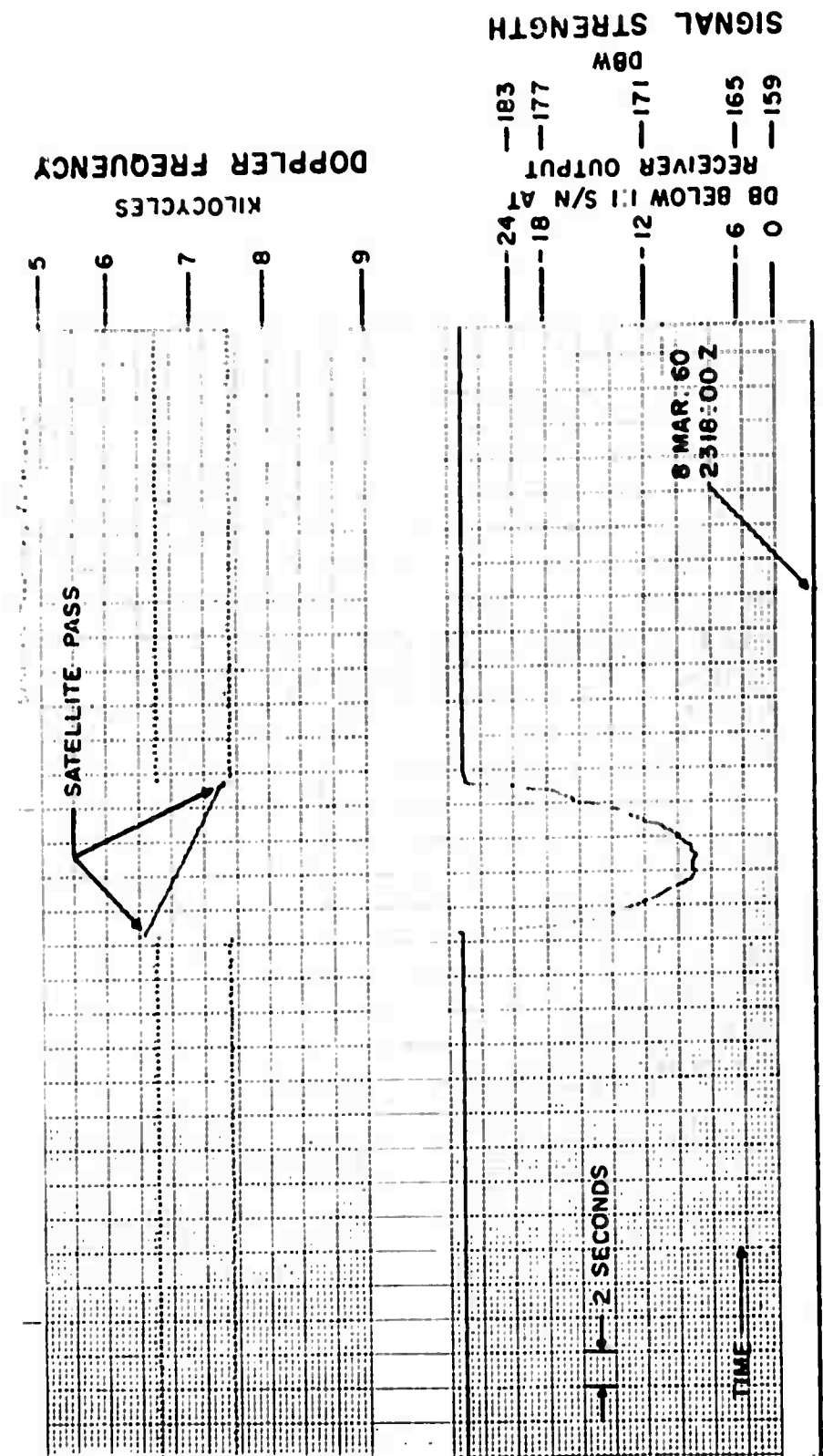
**ARPA-BRL DOPLOC DOPPLER RECORD OF
58 DELTA REV 9581, FORREST CITY, ARKANSAS**

MEASURED 2317:41 Z, PREDICTED 2317 Z
ALTITUDE 116 MILES, 33 MILES EAST FT SILL
CENTER ANTENNA, NORTH – SOUTH PASS

Fig. 28

DOPPLER FREQUENCY
KILOCYCLES

SIGNAL STRENGTH
DBW
RECEIVER OUTPUT
DB BELOW 1:1 S/N AT

SATELLITE PASS

10 MAR. 60
2219:00 Z

2 SECONDS

TIME
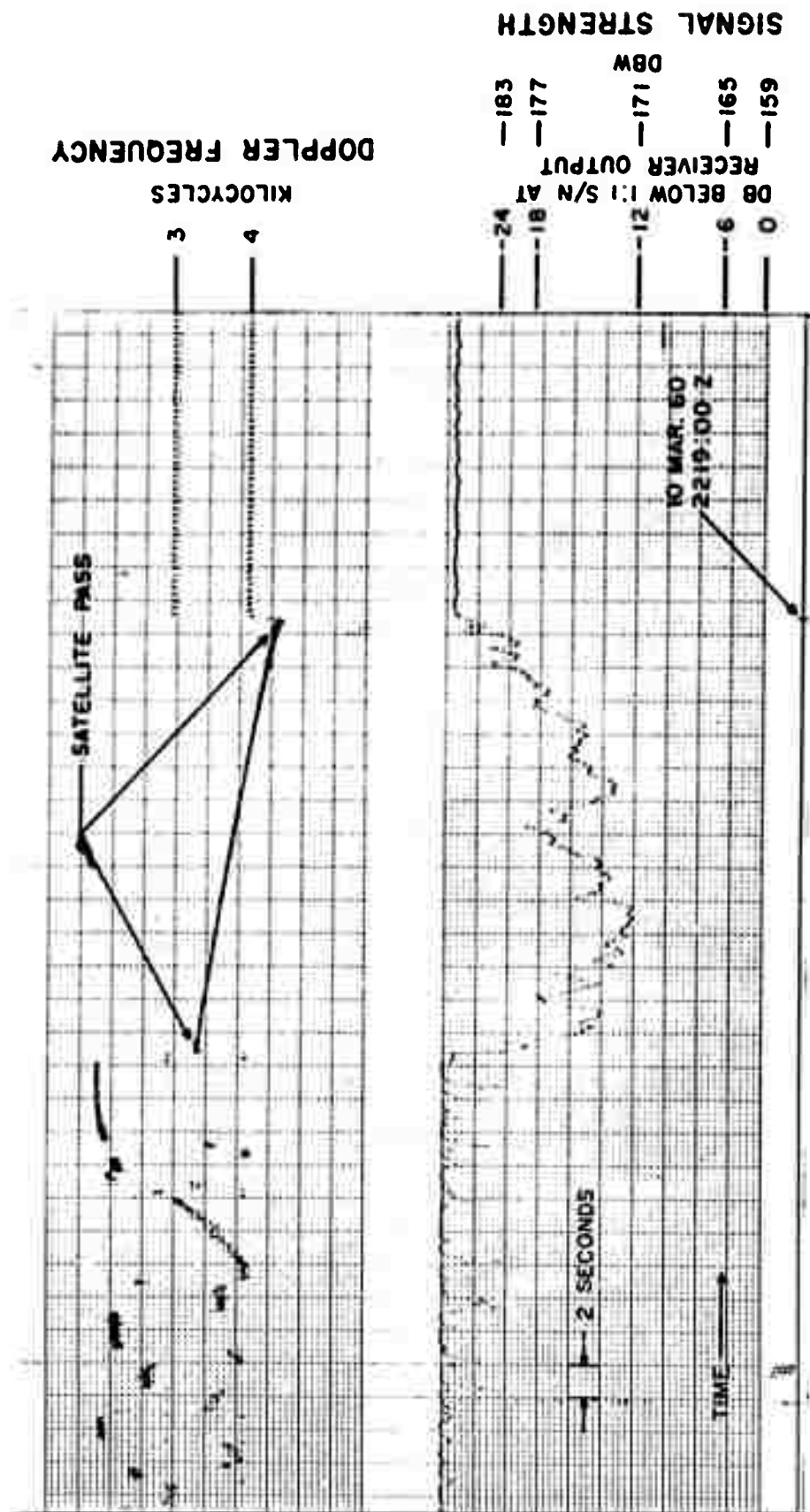
ARPA-BRL DOPLOC DOPPLER RECORD OF
58 DELTA REV 9612, FORREST CITY, ARKANSAS
MEASURED 2218:33 Z, PREDICTED 2220 Z
ALTITUDE 116 MILES, 328 MILES EAST FT. SILL
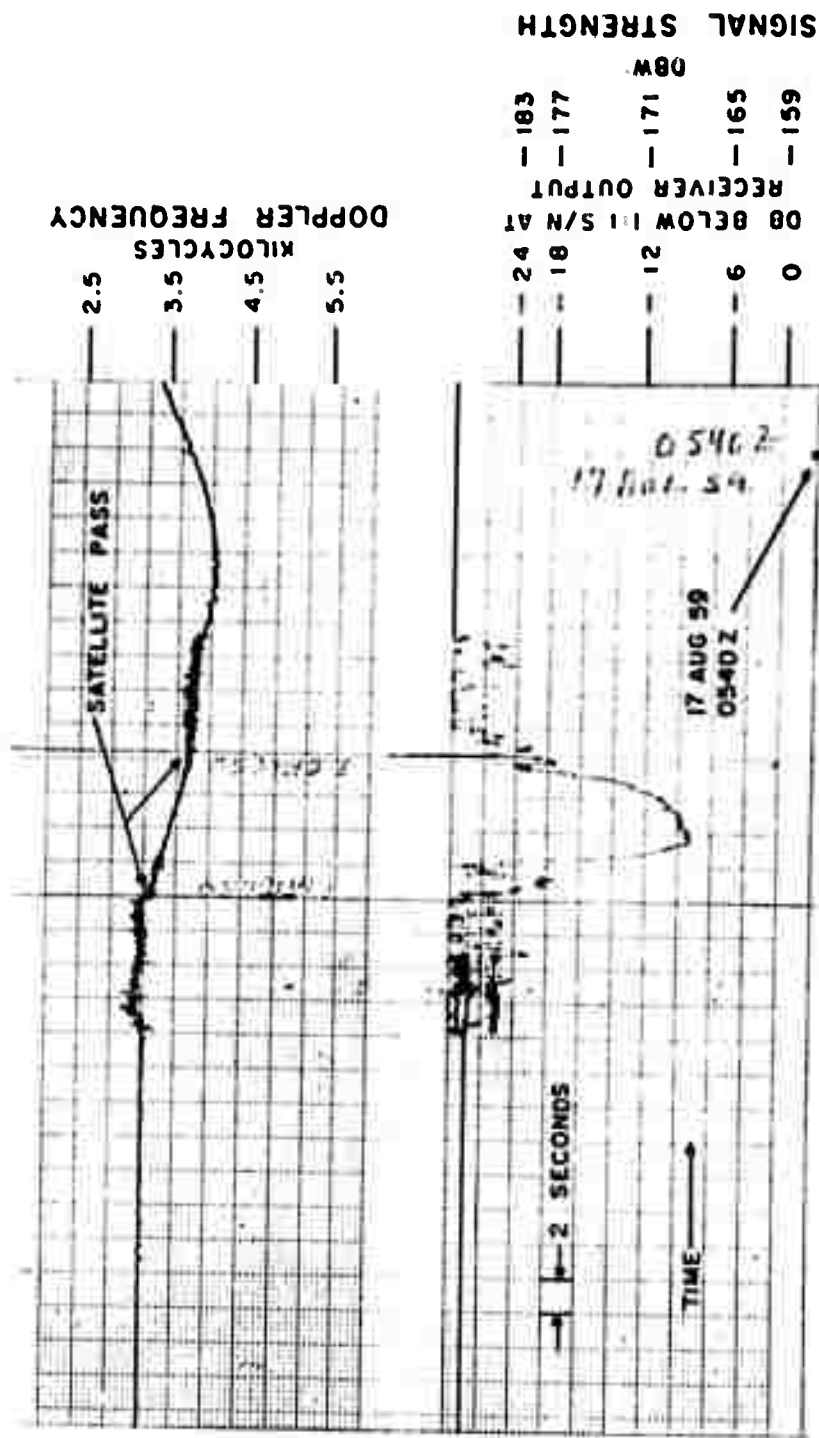NORTH ANTENNA, NORTH – SOUTH PASS

FIG. 29

85

ARPA – BRL DOPLOC DOPPLER RECORD OF
58 DELTA REV 9716, FORREST CITY, ARKANSAS

MEASURED 1114:54 Z, PREDICTED 1116 Z
ALTITUDE 285 MILES, 135 MILES EAST FT. SILL
CENTER ANTENNA, SOUTH–NORTH PASS

Fig. 30

SIGNAL STRENGTH
DBW

DOPPLER FREQUENCY
KILOCYCLES

ARPA – BRL DOPLOC DOPPLER RECORD OF
58 DELTA REV 9722, FORREST CITY, ARKANSAS

MEASURED 2044:31 Z, PREDICTED 2045 Z
ALTITUDE 113 MILES, 122 MILES WEST FT. SILL
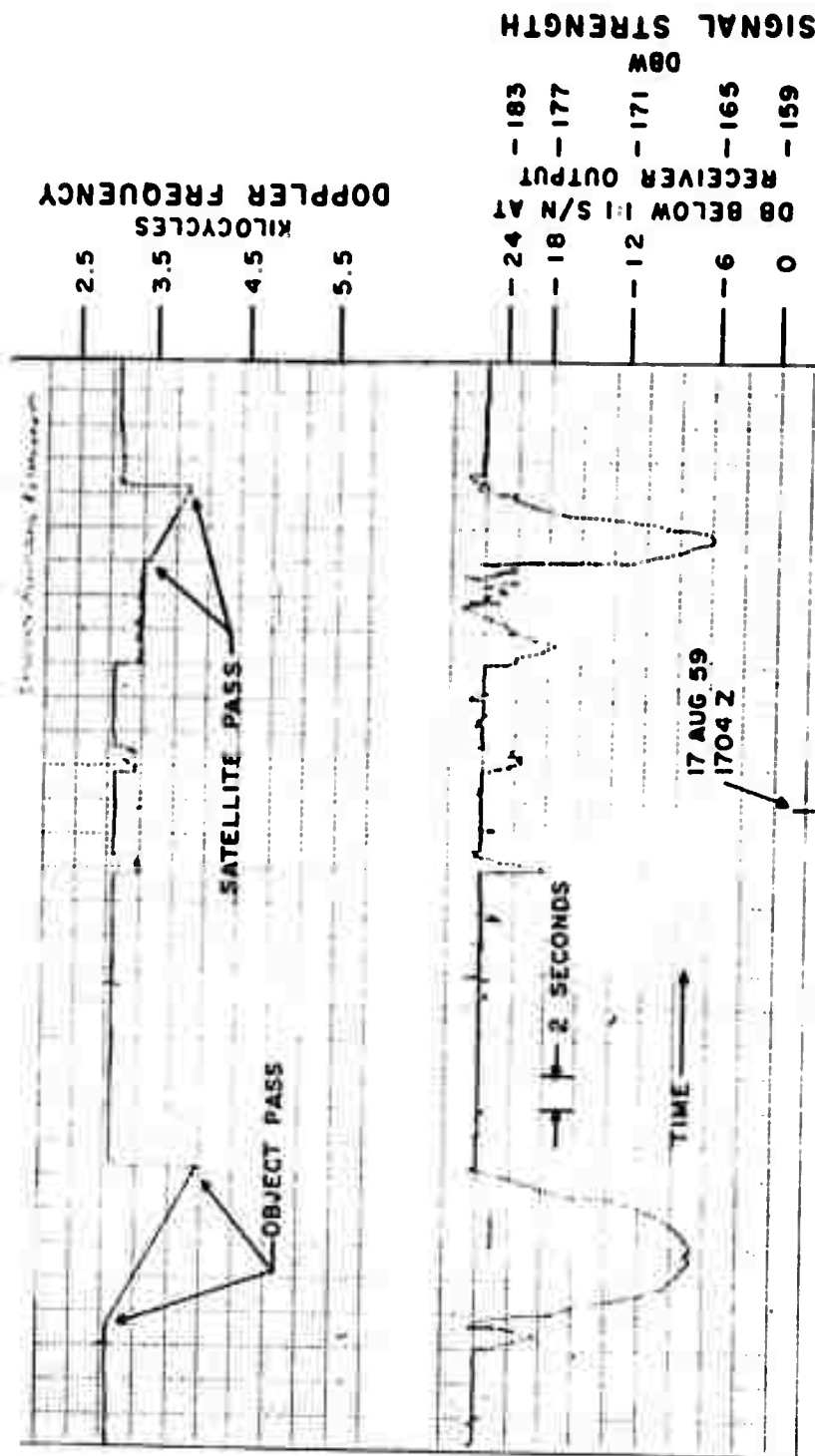SOUTH ANTENNA, NORTH – SOUTH PASS

Fig. 31

SIGNAL STRENGTH

DOPPLER FREQUENCY

ARPA - BRL DOPLOC DOPPLER RECORD OF
58 DELTA REV 9826, FORREST CITY, ARKANSAS
MEASURED 0847:25 Z, PREDICTED 0848 Z
ALTITUDE 189 MILES, 403 MILES EAST FT. SILL
CENTER ANTENNA, SOUTH – NORTH PASS

Fig. 32
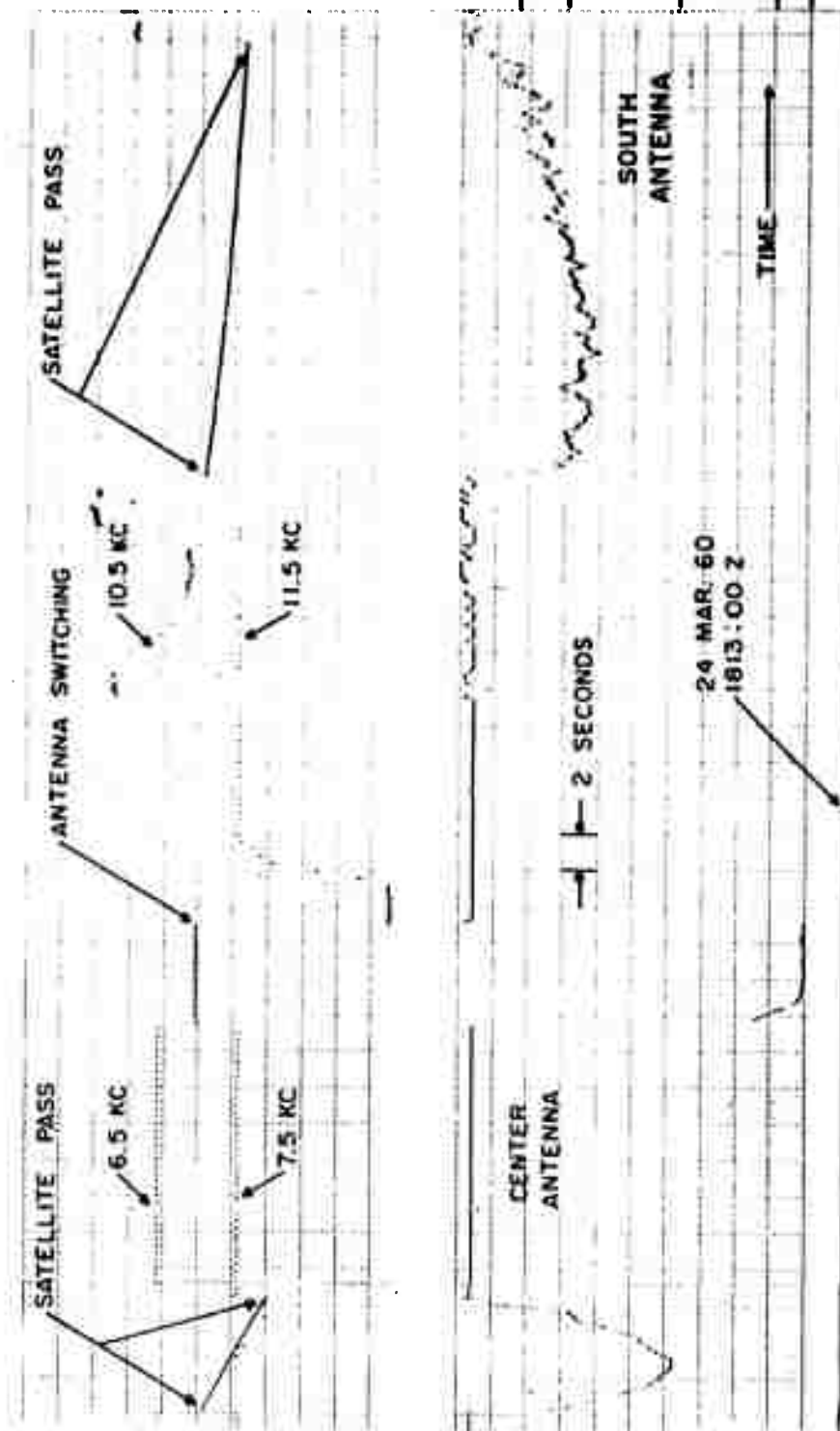
ARPA - BRL DOPLOC DOPPLER RECORD OF
58 DELTA REV 9832, FORREST CITY, ARKANSAS
MEASURED 1812:26 Z, PREDICTED 1813 Z
ALTITUDE 110 MILES, 244 MILES EAST FT. SILL
CENTER AND SOUTH ANTENNA, NORTH - SOUTH PASS

Fig. 33

SIGNAL STRENGTH

DBW

—183
—177
—171
—165
—159

DOPPLER FREQUENCY
KILOCYCLES

RECEIVER OUTPUT
DB BELOW 1:1 S/N AT

—24
—18
—12
—6
0

—2
—4
—6
—8
—10
—12
—13

SATELLITE PASS

2 SECONDS

25 MAR. 60
0849:00 Z

TIME
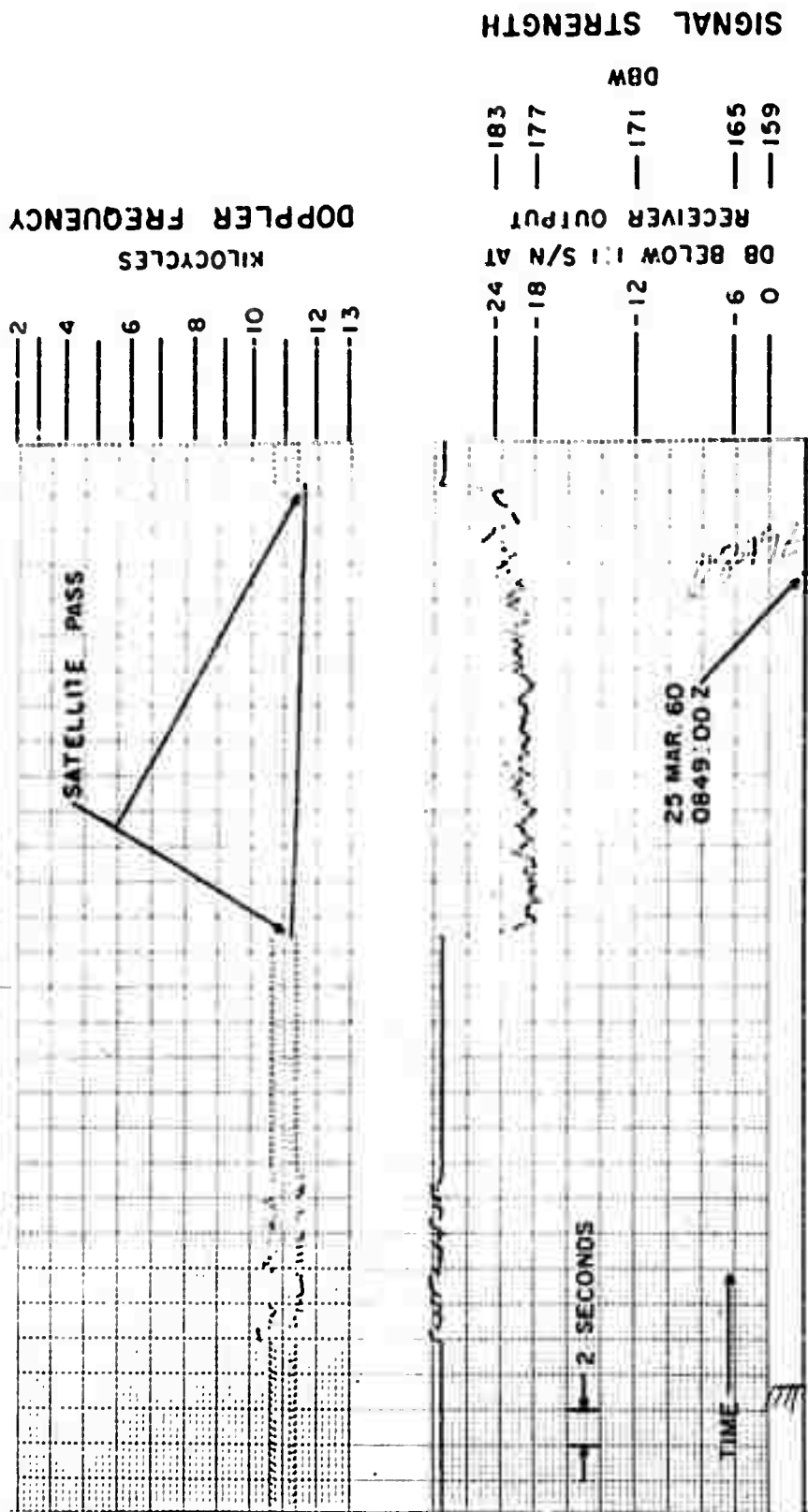
ARPA – BRL DOPLOC DOPPLER RECORD OF
58 DELTA REV 9642, FORREST CITY, ARKANSAS
MEASURED 0848:40 Z, PREDICTED 0848 Z
ALTITUDE 189 MILES, 137 MILES EAST FT. SILL
NORTH ANTENNA, SOUTH – NORTH PASS

Fig. 34

90
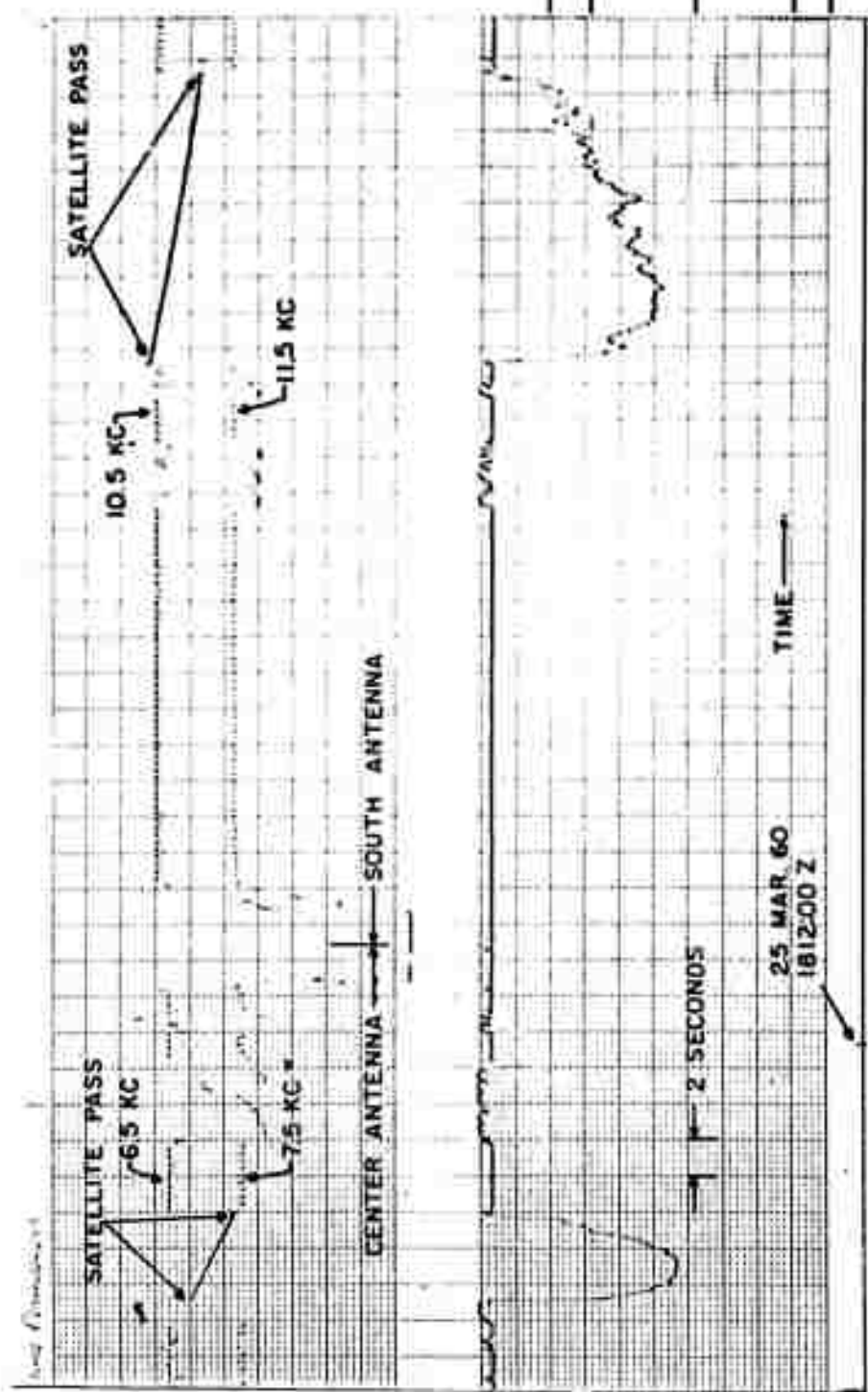
ARPA – BRL DOPLOC DOPPLER RECORD OF
58 DELTA REV. 9848, FORREST CITY, ARKANSAS

MEASURED 1811:46 Z, PREDICTED 1813 Z
ALTITUDE 109 MILES, OVERHEAD FT. SILL
CENTER AND SOUTH ANTENNA, NORTH–SOUTH PASS

Fig. 35

SIGNAL STRENGTH

DBW

183 — 177 — 171 — 165 — 159

RECEIVER OUTPUT

DB BELOW 1:1 S/N AT

24 — 18 — 12 — 6 — 0

DOPPLER FREQUENCY

KILOCYCLES

2.5 — 3.5

SATELLITE PASS

29. MAR. 60
0700-00 Z

TIME

2 SECONDS

**ARPA - BRL DOPLOC DOPPLER RECORD OF
58 DELTA REV 9905, FORREST CITY, ARKANSAS**

MEASURED 0659:58 Z, PREDICTED 0701 Z
ALTITUDE 171 MILES, 600 MILES EAST FT. SILL
SOUTH ANTENNA, SOUTH - NORTH PASS
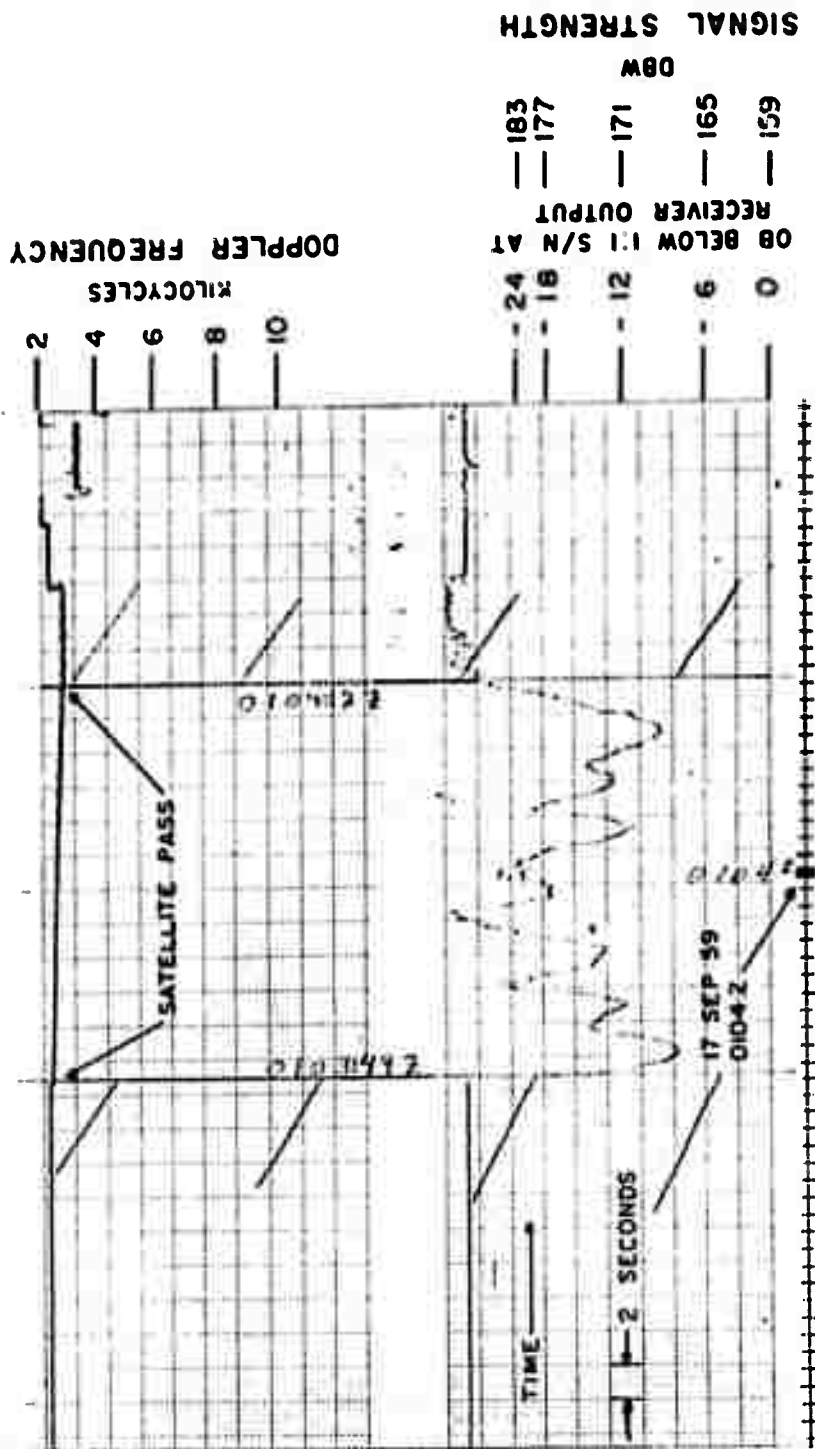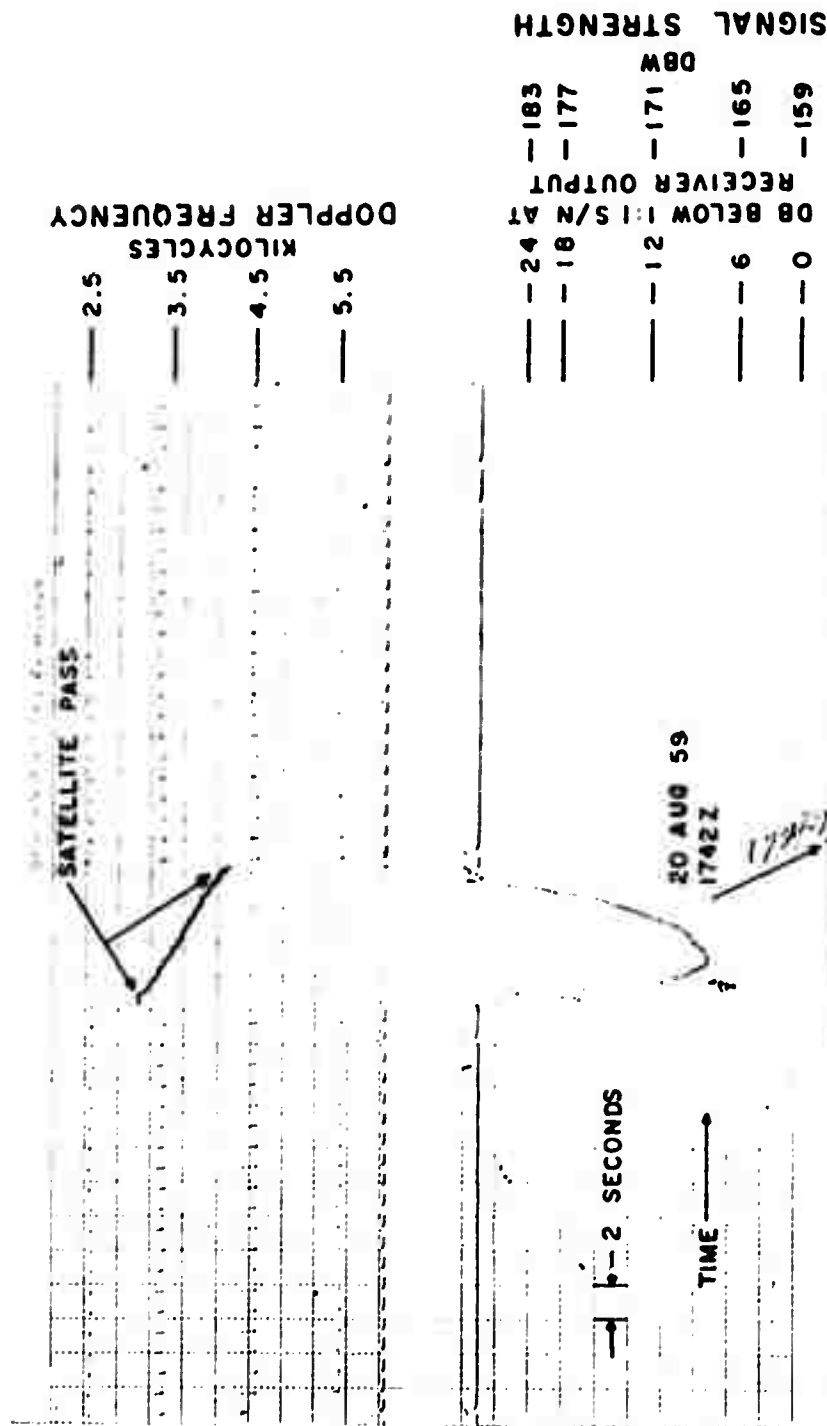
Fig. 36

92

SIGNAL STRENGTH

DOPPLER FREQUENCY
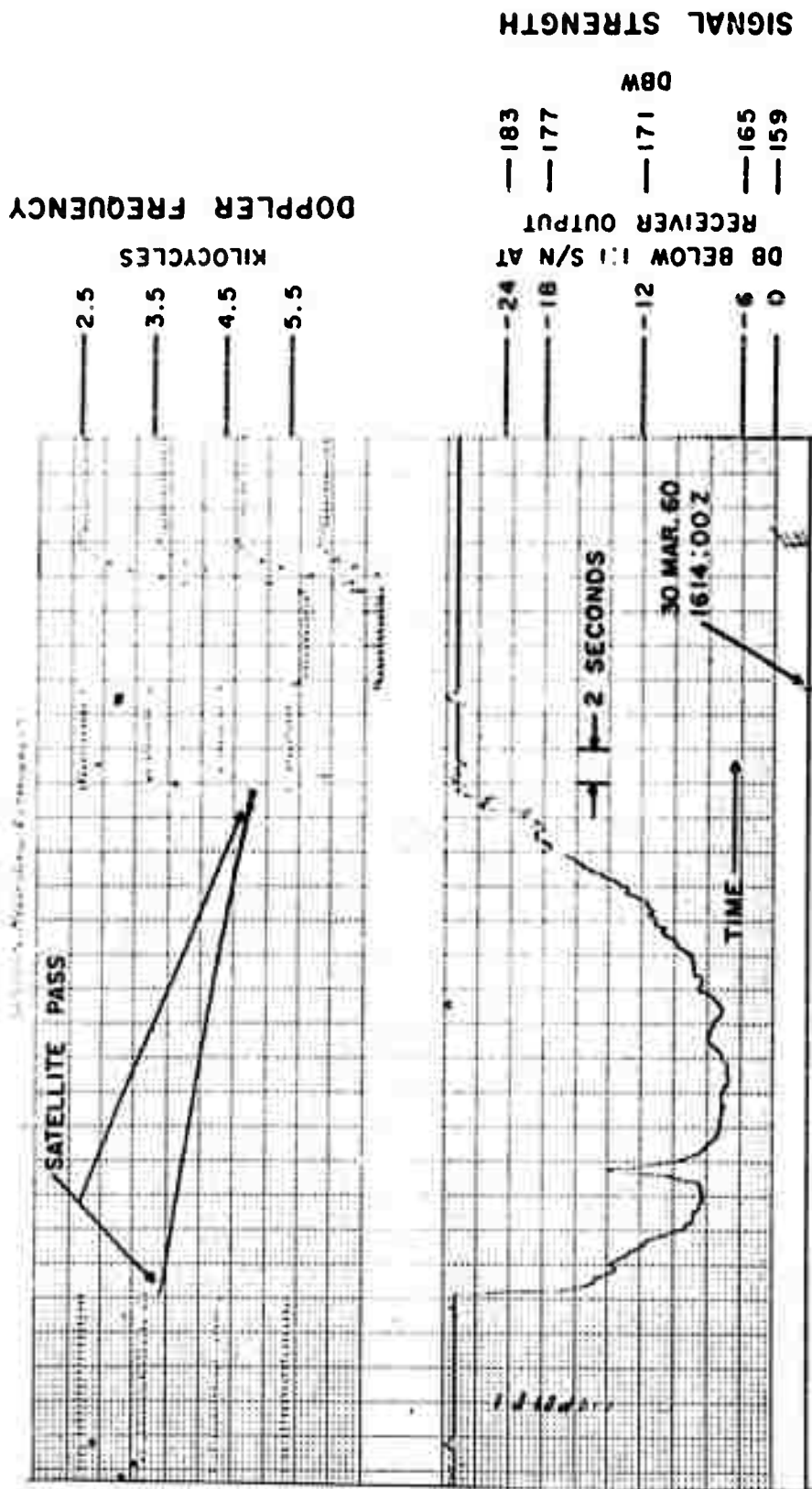
ARPA - BRL DOPLOC DOPPLER RECORD OF
58 DELTA REV 9927, FORREST CITY, ARKANSAS
MEASURED 1613:25 Z, PREDICTED 1614 Z
ALTITUDE 105 MILES, 375 MILES EAST FT. SILL
NORTH ANTENNA, NORTH - SOUTH PASS

Fig. 37

ARPA – ERL DOPLOC DOPPLER RECORD OF
30 DELTA REV. 8937, FORREST CITY, ARKANSAS
WEEKEND 0647.572, PREDICTED 0647.2
ALTITUDE 150 MILES, 340 MILES EAST OF TEL
SOUTH – CENTER – NORTH ANTENNAS, SOUTH – NORTH PASS

Fig. 38

DOPPLER FREQUENCY
KILOCYCLES

SIGNAL STRENGTH
DBW

ARPA – BRL DOPLOC DOPPLER RECORD OF
58 DELTA REV. 9943 , FORREST CITY, ARKANSAS
MEASURED 1601:53 Z , PREDICTED 1602 Z
ALTITUDE 105 MILES, 310 MILES EAST OF FT. SILL
NORTH AND CENTER ANTENNAS ,NORTH–SOUTH PASS

Fig. 39

95

ARPA—BRL DOPLOC DOPPLER RECORD OF
58 DELTA REV. 9959, FORREST CITY, ARKANSAS
MEASURED 1547:58 Z, PREDICTED 1547 Z
ALTITUDE 103 MILES, 266 MILES EAST OF FT. SILL
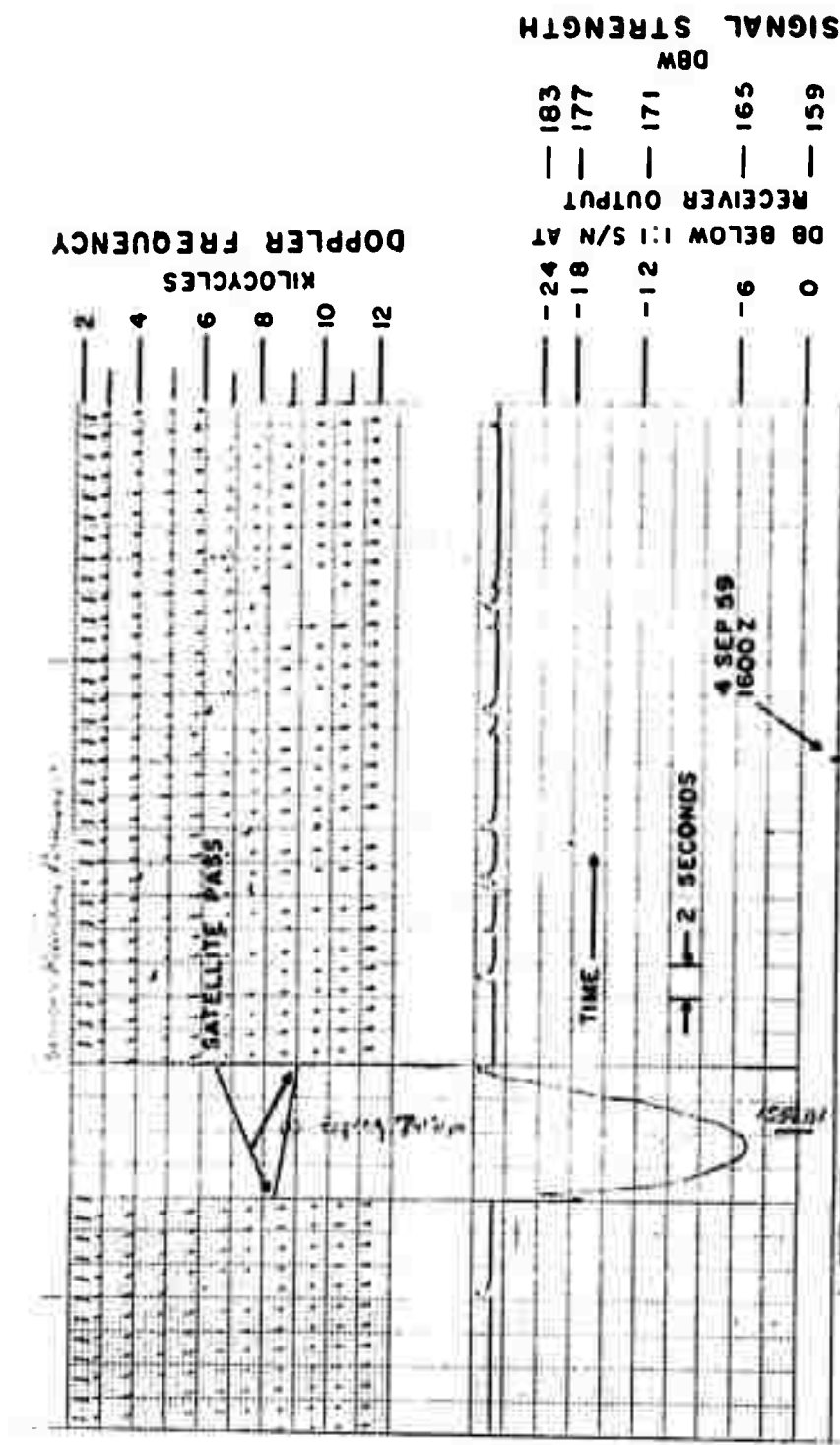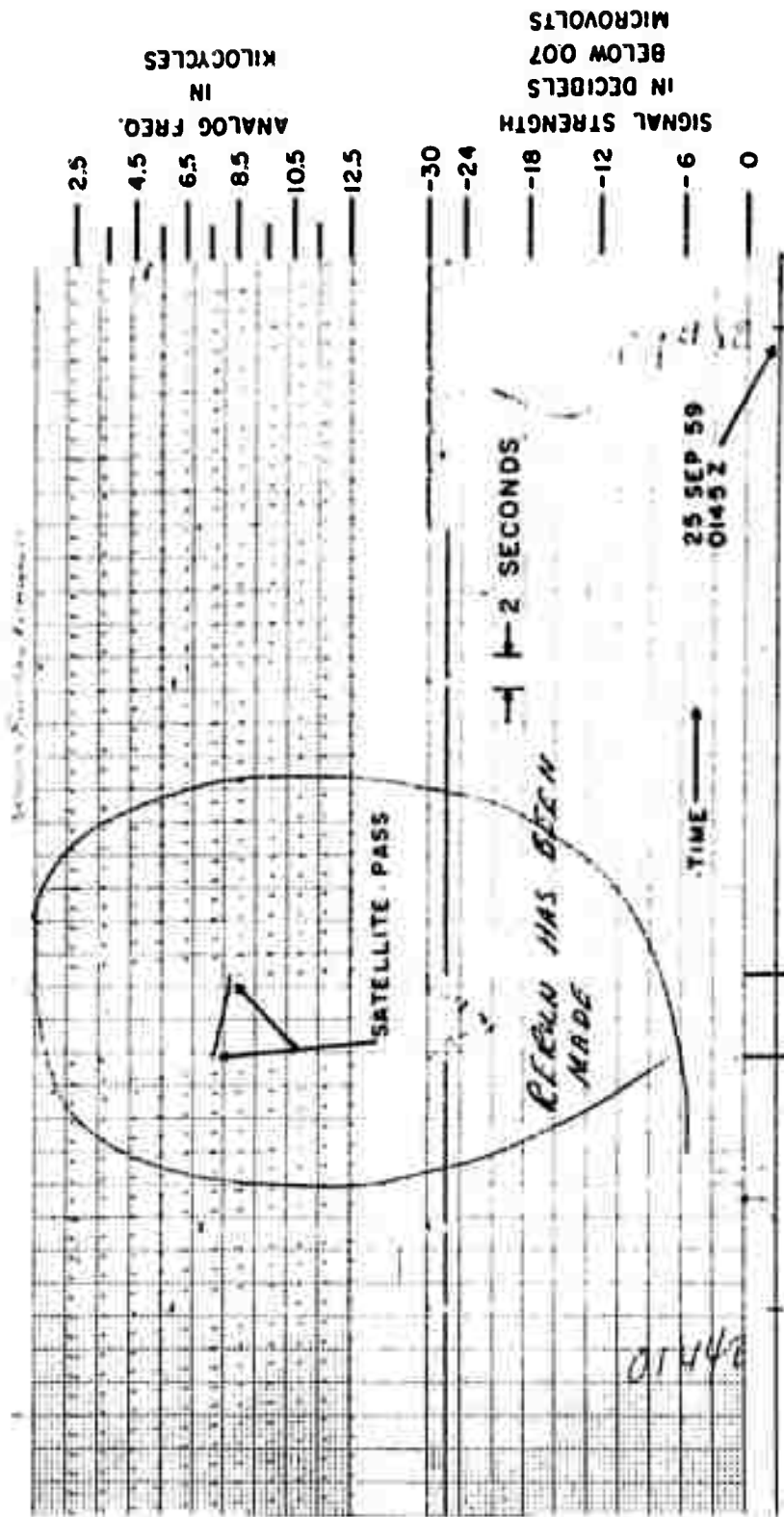NORTH ANTENNA, NORTH–SOUTH PASS

Fig. 40

SIGNAL STRENGTH
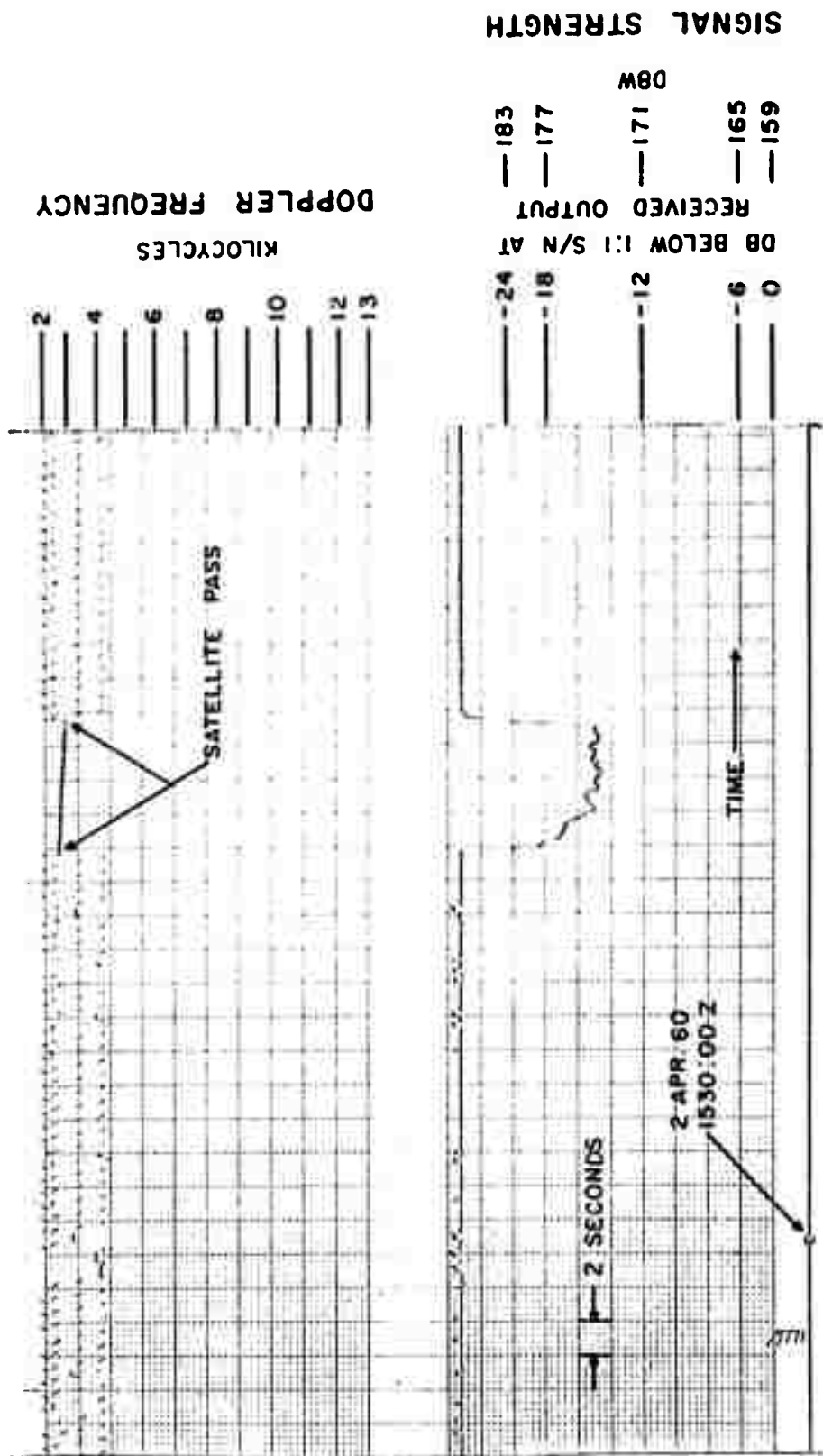
ARPA-BRL DOPLOC DOPPLER RECORD OF
58 DELTA REV 9975, FORREST CITY, ARKANSAS
MEASURED 1530:24 Z, PREDICTED 1531 Z
ALTITUDE 103 MILES, 211 MILES EAST FT. SILL
NORTH ANTENNA, NORTH - SOUTH PASS

Fig. 41

SIGNAL STRENGTH

DBW

DOPPLER FREQUENCY

KILOCYCLES

SATELLITE PASS

RECEIVER OUTPUT

DB BELOW 11 S/N AT

2-SECONDS

TIME

3 APR. 60
151000 Z

ARPA—BRL DOPLOC DOPPLER RECORD OF
58 DELTA REV. 9991, FORREST CITY, ARKANSAS
MEASURED 1509:18 Z, PREDICTED 1515 Z
ALTITUDE 95 MILES, 246 MILES EAST OF FT. SILL
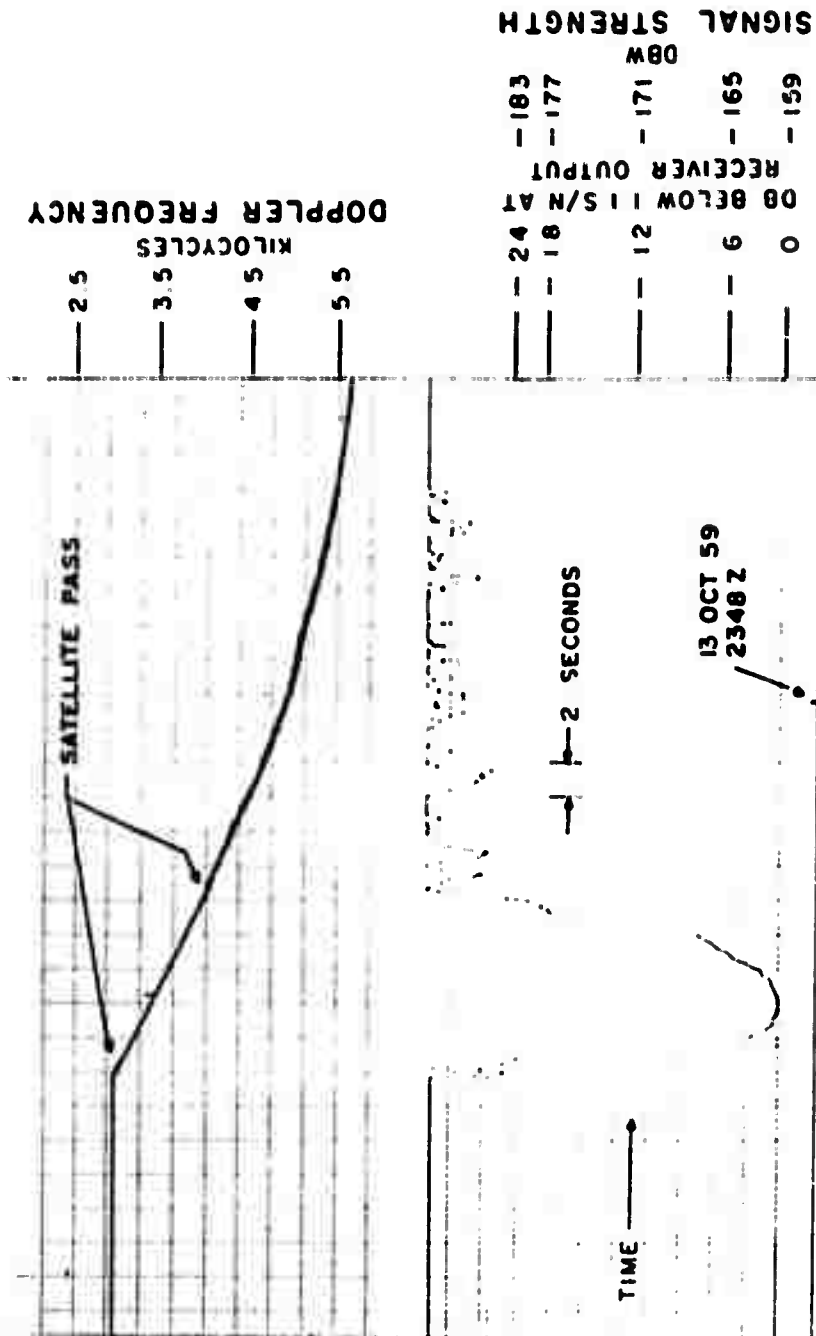NORTH ANTENNA, NORTH—SOUTH PASS

Fig. 42

SIGNAL STRENGTH
DBM

DOPPLER FREQUENCY
KILOCYCLES

SATELLITE PASS

CENTER ANTENNA

SOUTH ANTENNA

SATELLITE PASS

2 SECONDS

RECEIVER OUTPUT
DB BELOW II S/N AT

TIME

4 APR 60
0530:00 Z

ARPA—BRL DOPLOC DOPPLER RECORD OF
58 DELTA REV. 10001 , FORREST CITY, ARKANSAS
MEASURED 0530:49 Z . PREDICTED 0537 Z
ALTITUDE 124 MILES, 285 MILES EAST OF FT. SILL
SOUTH AND CENTER ANTENNAS, SOUTH—NORTH PASS

Fig. 43

99

SIGNAL STRENGTH

DBW

SATELLITE PASS

DOPPLER FREQUENCY

KILOCYCLES

RECEIVER OUTPUT

DB BELOW 1:1 S/N AT

4 APR. 60
1445:00 Z

2 SECONDS

TIME

ARPA–BRL DOPLOC DOPPLER RECORD OF
58 DELTA REV 10007, FORREST CITY, ARKANSAS
MEASURED 1444:37, PREDICTED 1454 Z
ALTITUDE 95 MILES, 380 MILES EAST FT. SILL
NORTH ANTENNA, NORTH – SOUTH PASS

Fig. 44

SIGNAL STRENGTH

DOPPLER FREQUENCY
KILOCYCLES
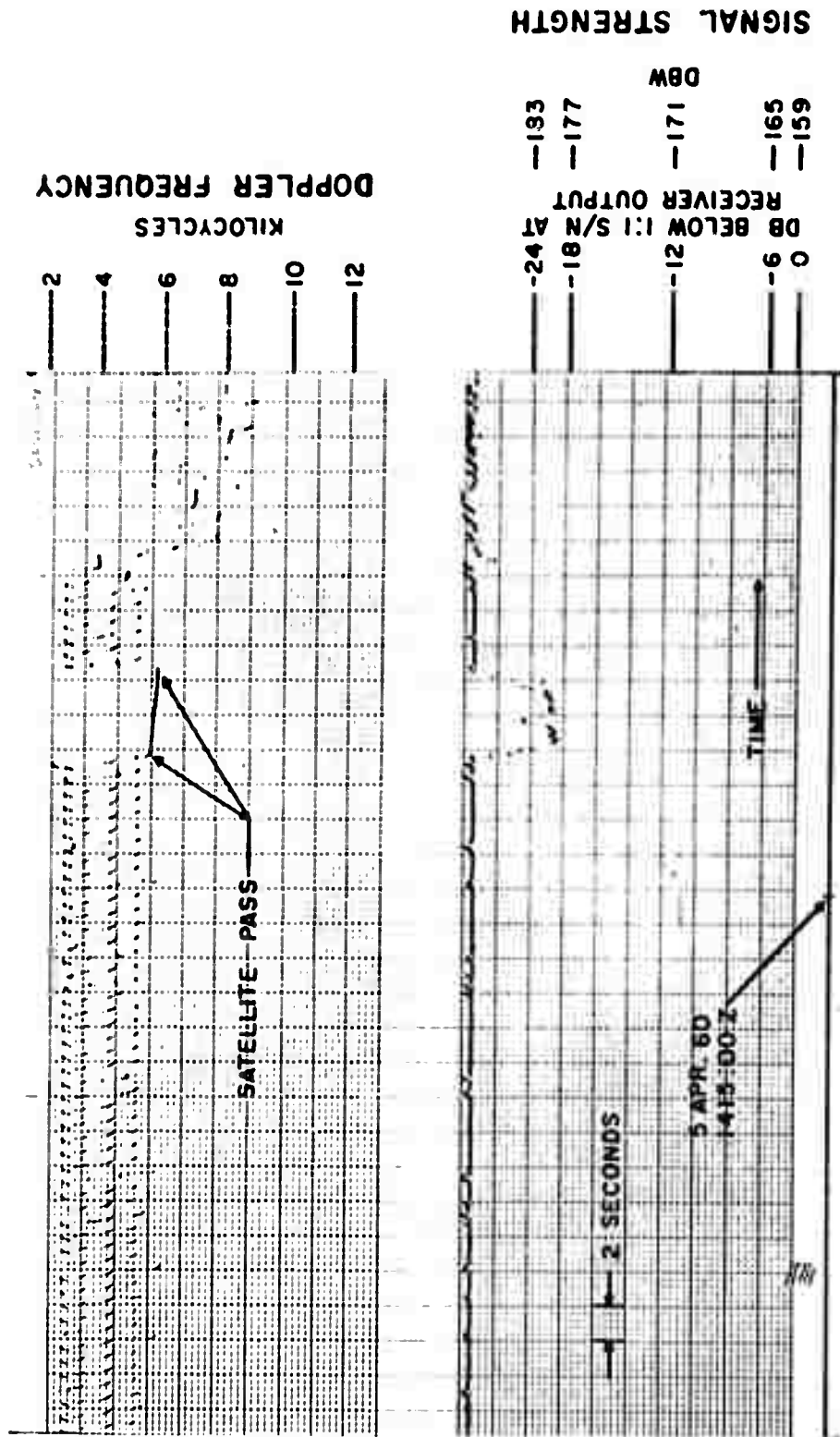
ARPA-BRL DOPLOC DOPPLER RECORD OF
58 DELTA REV 10023, FORREST CITY, ARKANSAS

MEASURED 1415:08 Z, PREDICTED 1408 Z
ALTITUDE 95 MILES, 600 MILES EAST FT. SILL
NORTH ANTENNA, NORTH - SOUTH PASS

SATELLITE - PASS

5 APR. 60
1415:00 Z

2 SECONDS

TIME

Fig. 45

ARPA-BRL DOPLOC DOPPLER RECORD OF
59 EPSILON REV. 53, FORREST CITY, ARKANSAS
MEASURED 0539:34 Z, PREDICTED 0536 Z
ALTITUDE 341 MILES, 279 MILES EAST FT. SILL
CENTER ANTENNA, SOUTH—NORTH PASS

Fig. 46

ARPA-BRL DOPLOC DOPPLER RECORD OF UNIDENTIFIED
OBJECT AND 59 EPSILON FORREST CITY, ARKANSAS

UNIDENTIFIED OBJECT
MEASURED 1703:30 Z, CENTER ANTENNA
ALTITUDE 125 MILES, OVERHEAD FT. SILL

59 EPSILON REV. 60
MEASURED 1704:14 Z, PREDICTED 1701 Z
ALTITUDE 140 MILES, 76 MILES WEST FT. SILL
CENTER ANTENNA, N-S PASS

Fig. 47
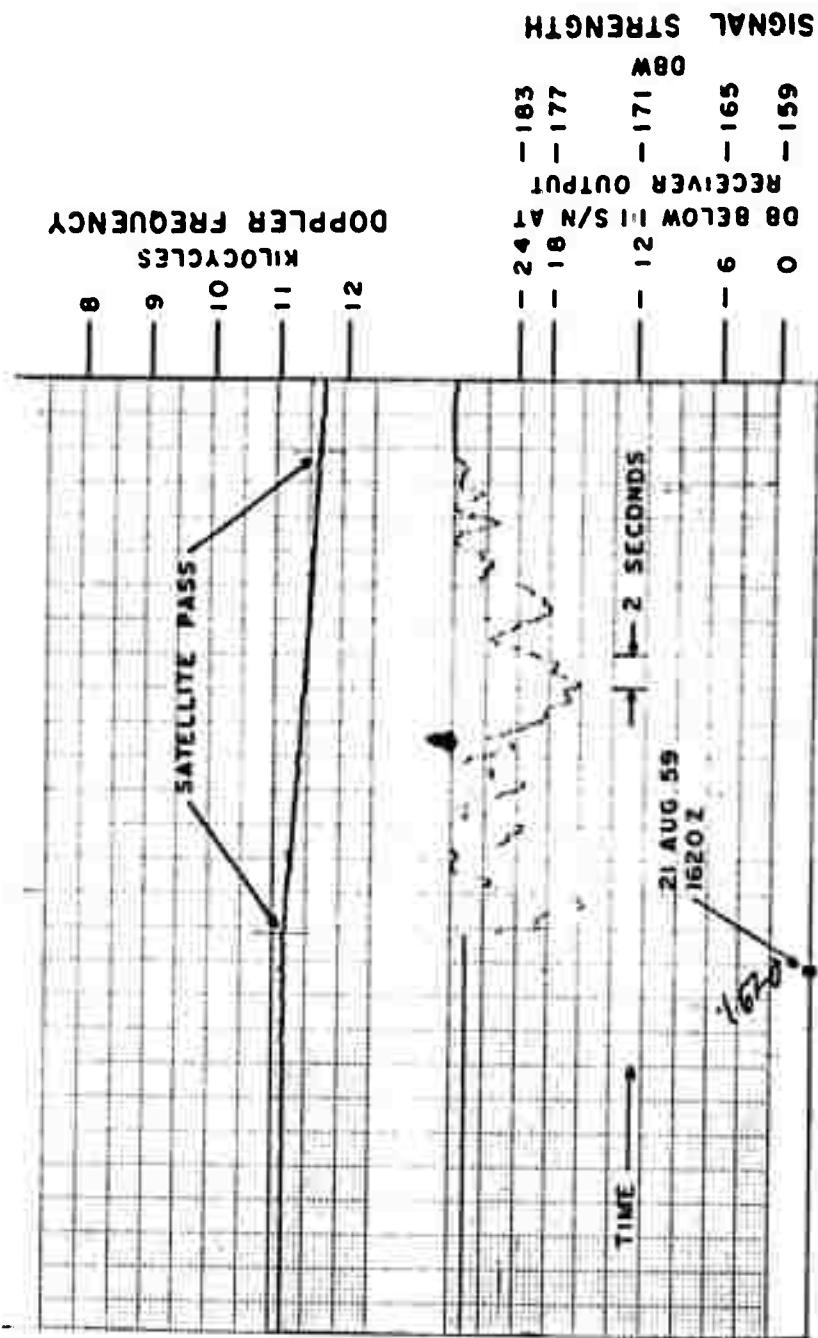
ARPA – BRL DOPLOC DOPPLER RECORD OF
59 EPSILON REV. 121, FORREST CITY, ARKANSAS
MEASURED 1620:02 Z, PREDICTED 1616 Z
ALTITUDE 140 MILES, 100 MILES EAST FT. SILL
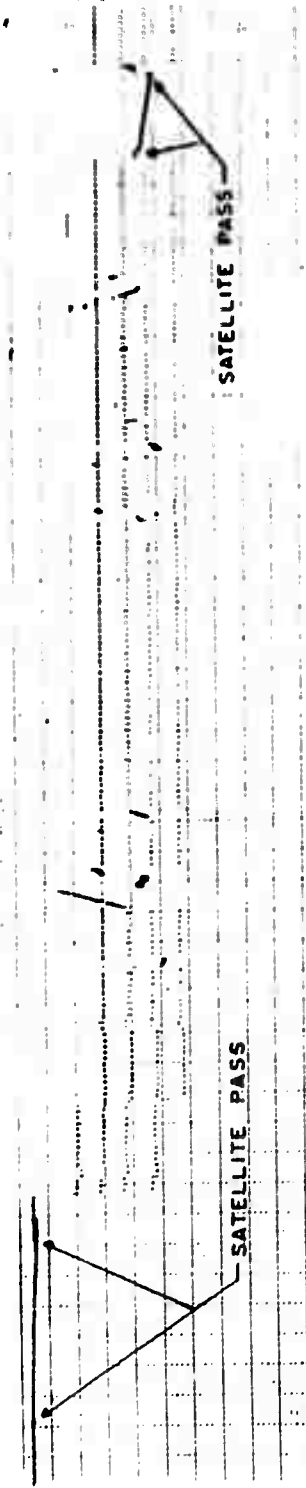SOUTH ANTENNA. NORTH–SOUTH PASS

Fig. 48
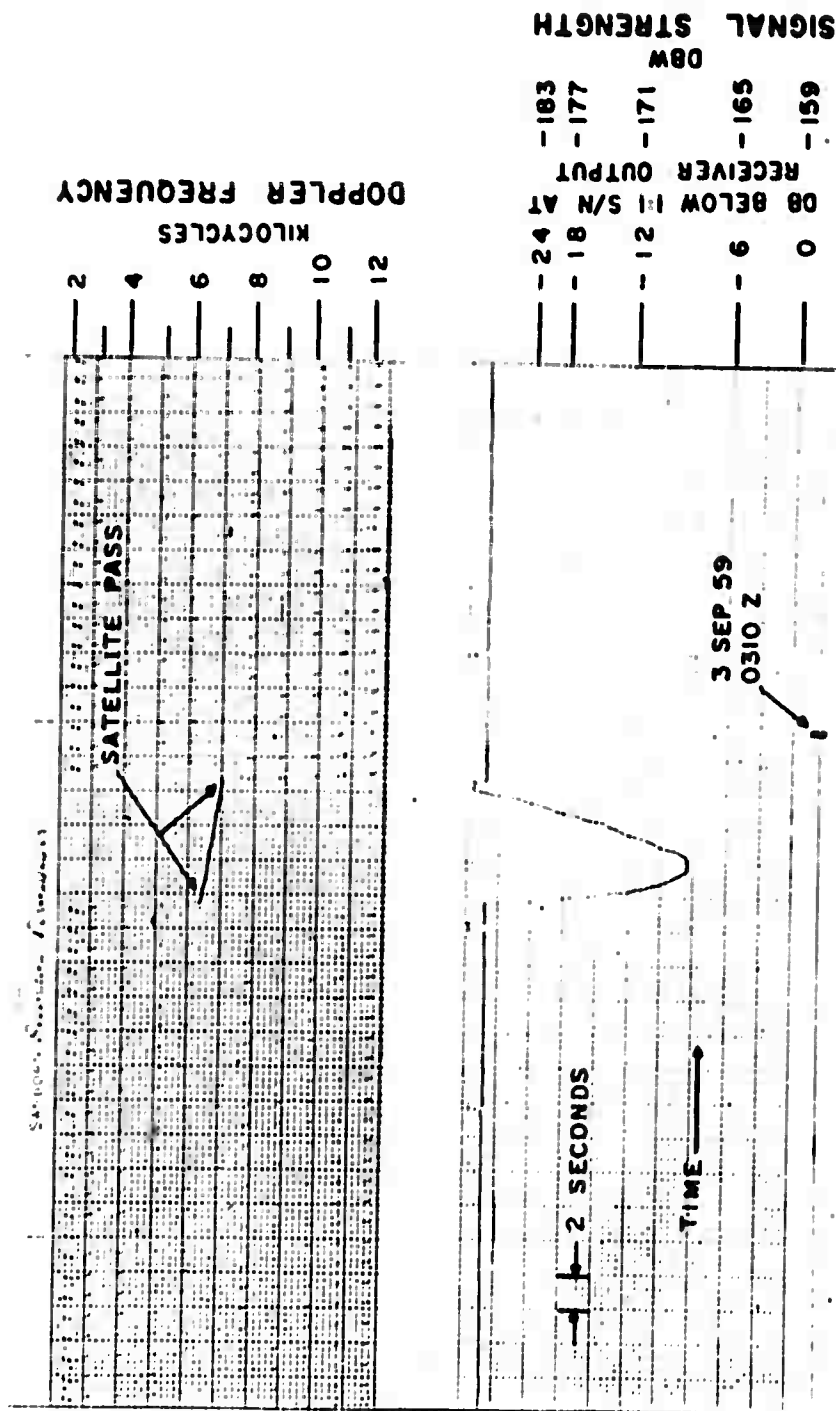
ARPA - BRL DOPLOC DOPPLER RECORD OF
59 EPSILON REV. 314, FORREST CITY, ARKANSAS
MEASURED 0309:50 Z, PREDICTED 0311 Z
ALTITUDE 185 MILES, 191 MILES EAST FT. SILL
CENTER ANTENNA, SOUTH — NORTH PASS
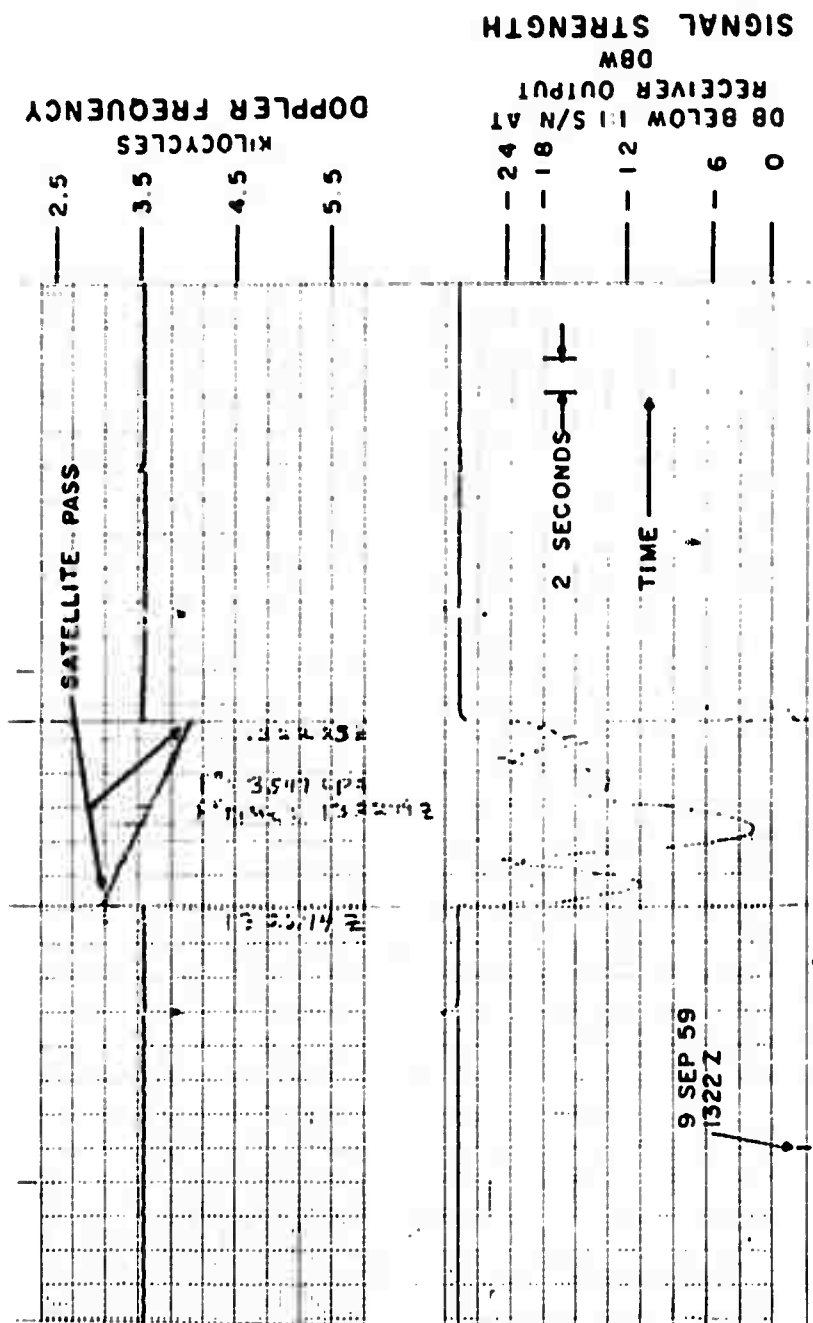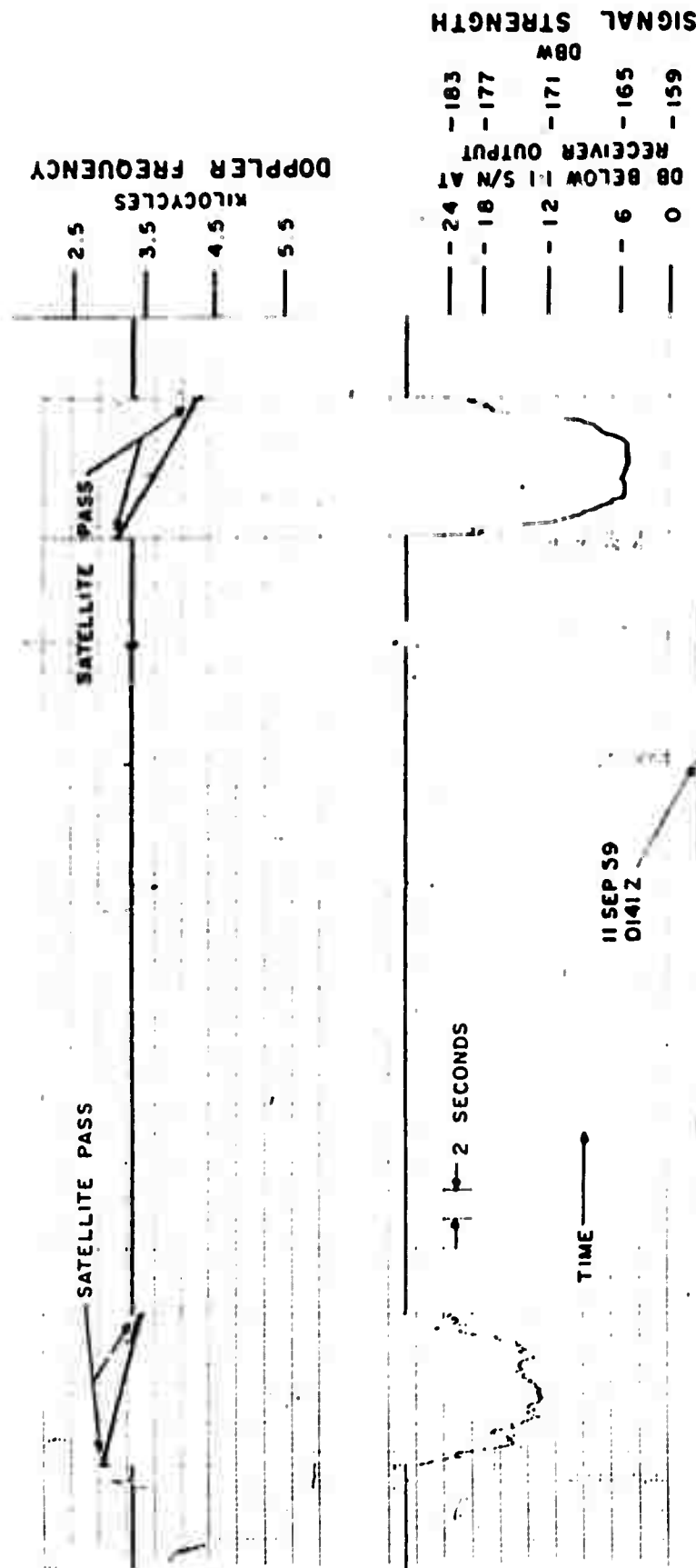
Fig. 49

ARPA-BRL DOPLOC DOPPLER DOPPLER RECORD OF
59 EPSILON REV. 414, FORREST CITY, ARKANSAS
MEASURED 1322:14 Z, PREDICTED 1324 Z
ALTITUDE 211 MILES, 17 MILES WEST FT. SILL
CENTER ANTENNA, NORTH-SOUTH PASS

Fig. 50

ARPA-BRL DOPLOC DOPPLER RECORD OF 58 DELTA
AND 59 EPSILON FORREST CITY, ARKANSAS

58 DELTA REV. 6844

MEASURED 0140:12 Z, PREDICTED 0138 Z
ALTITUDE 407 MILES, 283 MILES EAST FT. SILL
CENTER ANTENNA, NORTH-SOUTH PASS

59 EPSILON REV. 438

MEASURED 0141:16 Z, PREDICTED 0140 Z
ALTITUDE 150 MILES, 313 MILES EAST FT. SILL
CENTER ANTENNA, SOUTH-NORTH PASS

Fig. 51

ARPA - BRL DOPLOC DOPPLER RECORD OF
59 EPSILON REV. 532, FORREST CITY, ARKANSAS

MEASURED 0103 : 49Z, PREDICTED 0106Z
ALTITUDE 122 MILES, 32 MILES WEST FT. SILL
SOUTH ANTENNA, SOUTH - NORTH PASS

Fig. 52

SIGNAL STRENGTH
DBW

DOPPLER FREQUENCY
KILOCYCLES

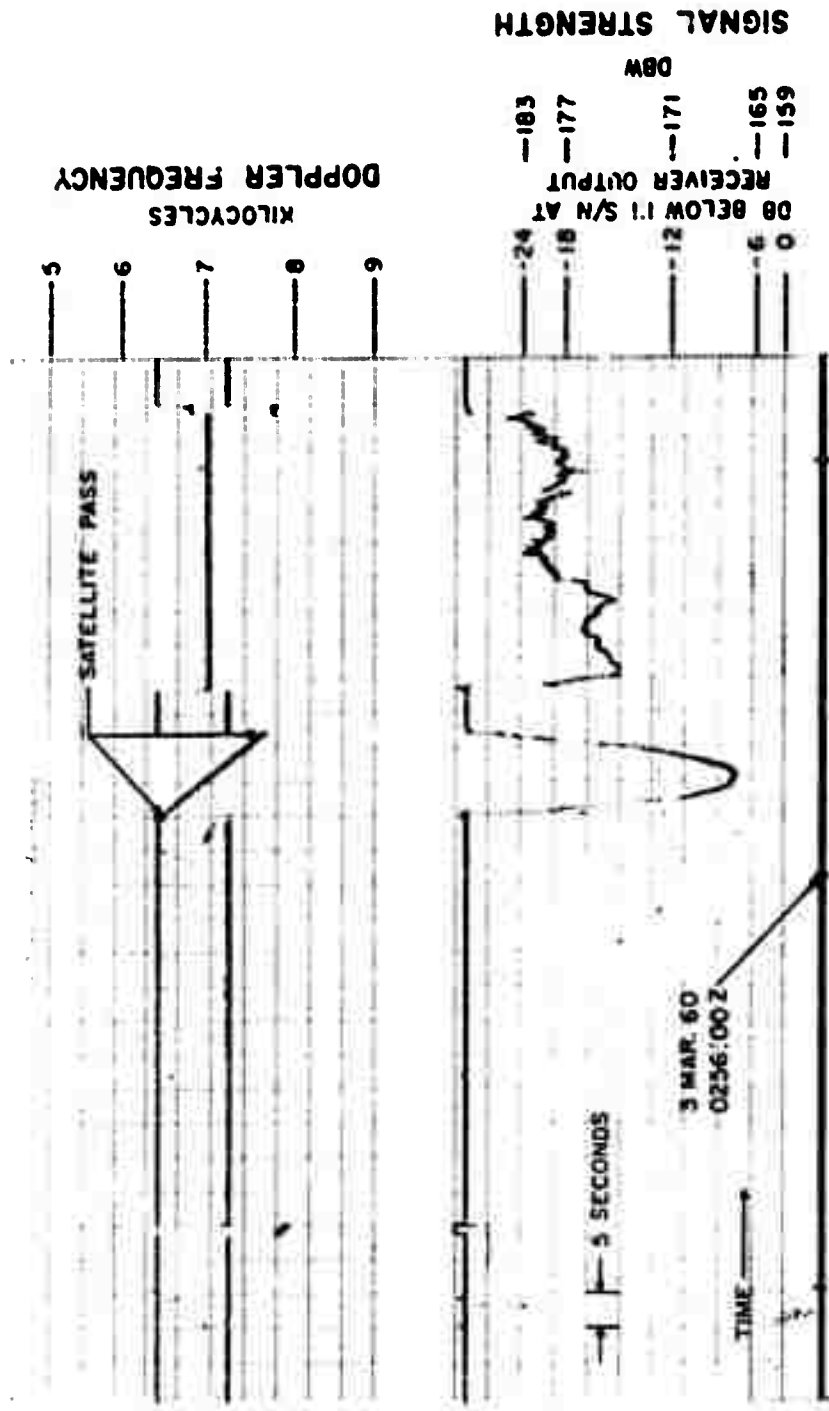ARPA-BRL DOPLOC DOPPLER RECORD OF
59 ZETA REV. 14, FORREST CITY, ARKANSAS
MEASURED 1741:51 Z, PREDICTED 1745 Z
ALTITUDE 136 MILES, 145 MILES EAST FT. SILL
CENTER ANTENNA, NORTH-SOUTH PASS

Fig. 53

109

DOPPLER FREQUENCY
KILOCYCLES

SIGNAL STRENGTH
DBW

2 SECONDS

TIME

29 AUG 59
1650 Z

1650 Z

SATELLITE PASS
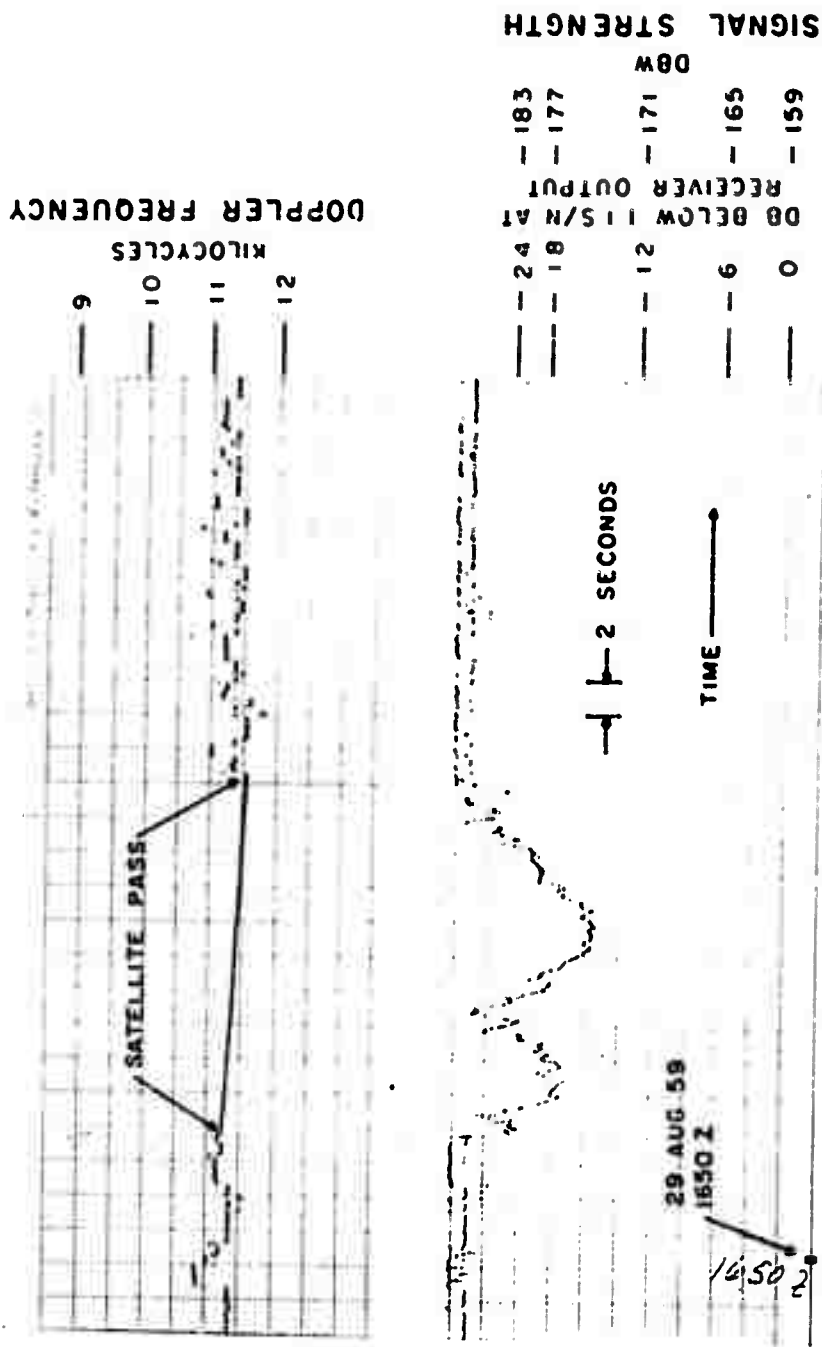
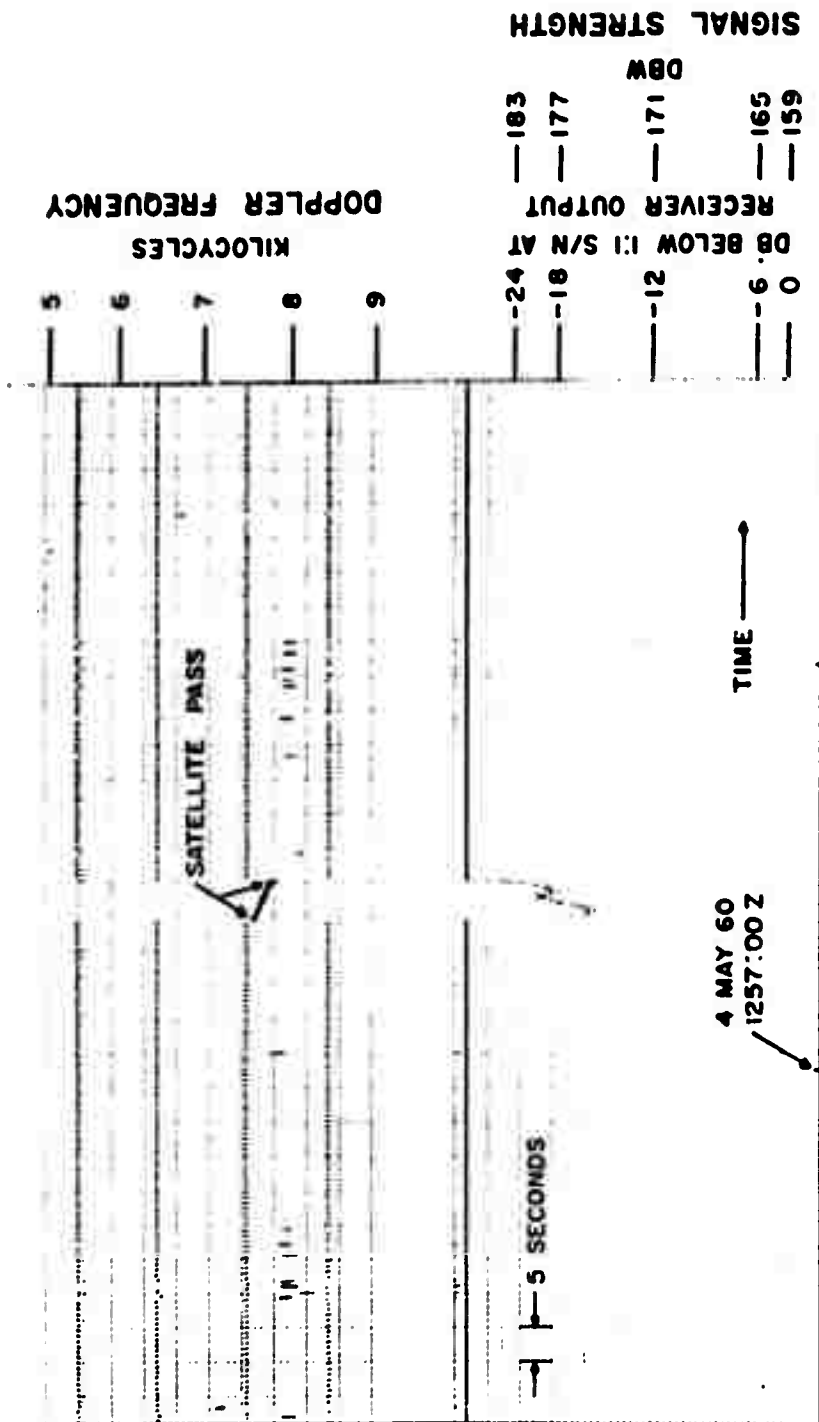ARPA - BRL DOPLOC DOPPLER RECORD OF
59 ZETA REV. 150, FORREST CITY, ARKANSAS
MEASURED 1650:07 Z, PREDICTED 1648 Z
ALTITUDE 171 MILES, 15 MILES EAST FT. SILL
SOUTH ANTENNA, NORTH-SOUTH PASS

FIG. 54

SIGNAL STRENGTH
DBW

DOPPLER FREQUENCY
KILOCYCLES

SATELLITE PASS

TIME

2 SECONDS

4 SEP 59
1600 Z

ARPA - BRL DOPLOC DOPPLER RECORD OF
59 ZETA REV. 241, FORREST CITY, ARKANSAS
MEASURED 1559 : 34 Z, PREDICTED 1601 Z
ALTITUDE 213 MILES, 123 MILES EAST FT. SILL
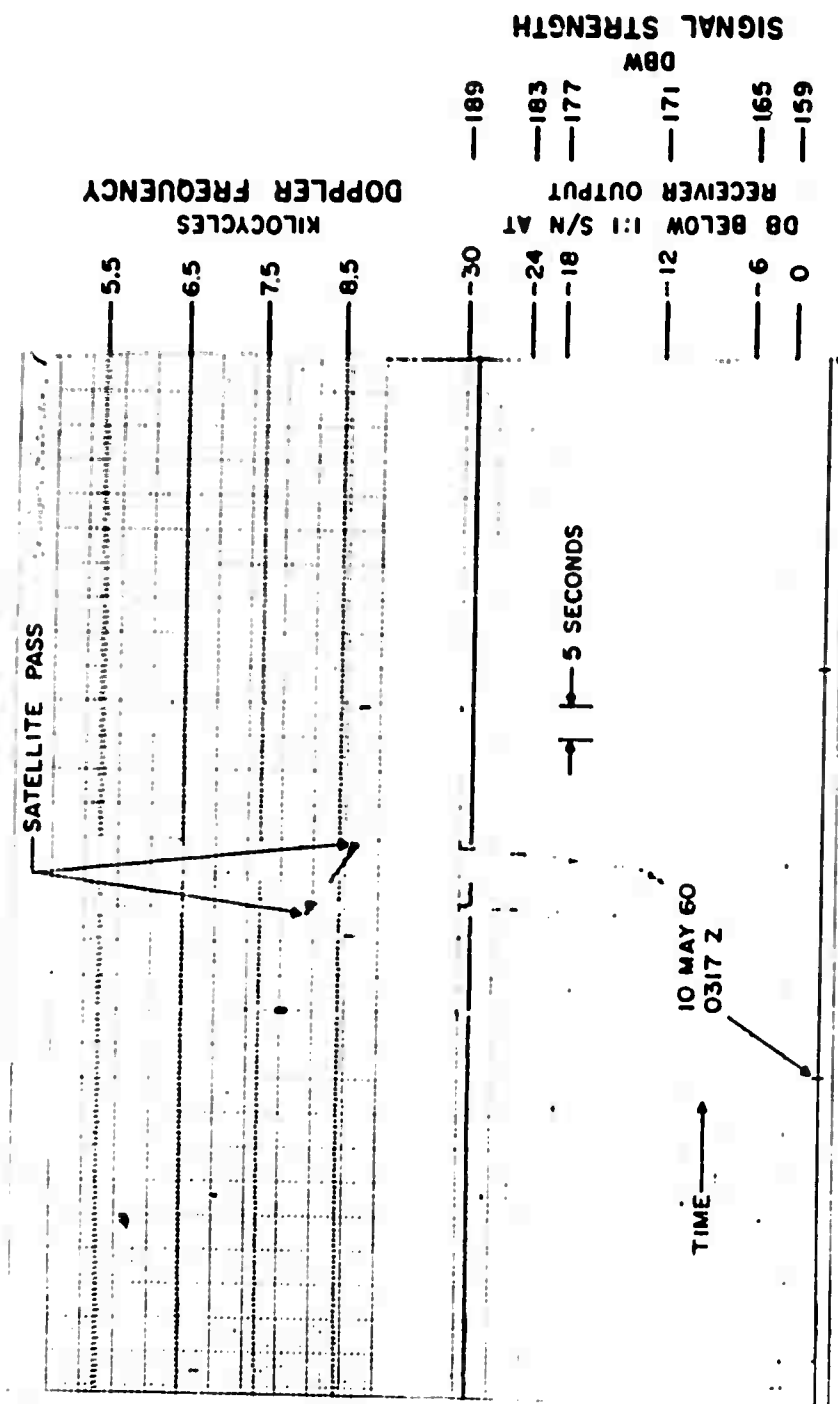CENTER ANTENNA, NORTH - SOUTH PASS

Fig. 55

ANALOG FREQ. IN KILOCYCLES

SIGNAL STRENGTH IN DECIBELS BELOW 0.007 MICROVOLTS

SATELLITE PASS

REERUN HAS BEEN MADE

2 SECONDS

TIME

01:44:21 Z

01:44:16 Z

25 SEP 59 01:45 Z

01:44:16 Z TIME 25 SEP 59

ARPA — BRL DOPLOC DOPPLER RECORD OF
59 ZETA REV 556 FORREST CITY, ARKANSAS
MEASURED 01:44:16 Z, PREDICTED 01:46 Z
ALTITUDE 147 MILES, 339 MILES EAST FT. SILL
CENTER ANTENNA, DIRECTION S-N

FIG. 56

112

SIGNAL STRENGTH

DOPPLER FREQUENCY
KILOCYCLES

SATELLITE PASS

2 SECONDS

13 OCT 59
2348 Z

TIME

ARPA-BRL DOPLOC DOPPLER RECORD OF
59 ZETA REV. 855, FORREST CITY, ARKANSAS
MEASURED 2347:38 Z, PREDICTED 2346 Z
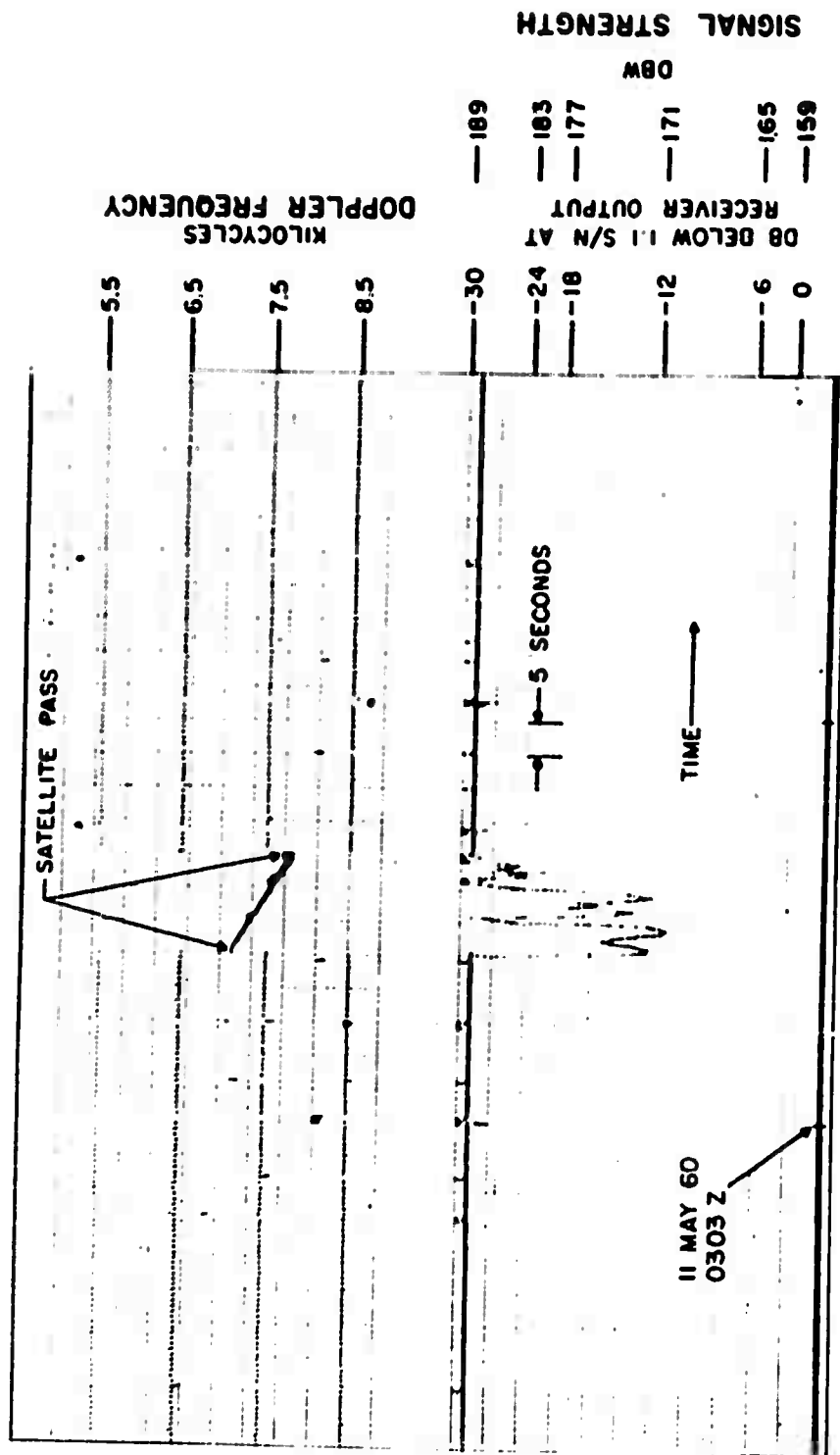ALTITUDE 138 MILES, 179 MILES EAST FT. SILL
CENTER ANTENNA, SOUTH-NORTH PASS

Fig. 57

SIGNAL STRENGTH

DOPPLER FREQUENCY
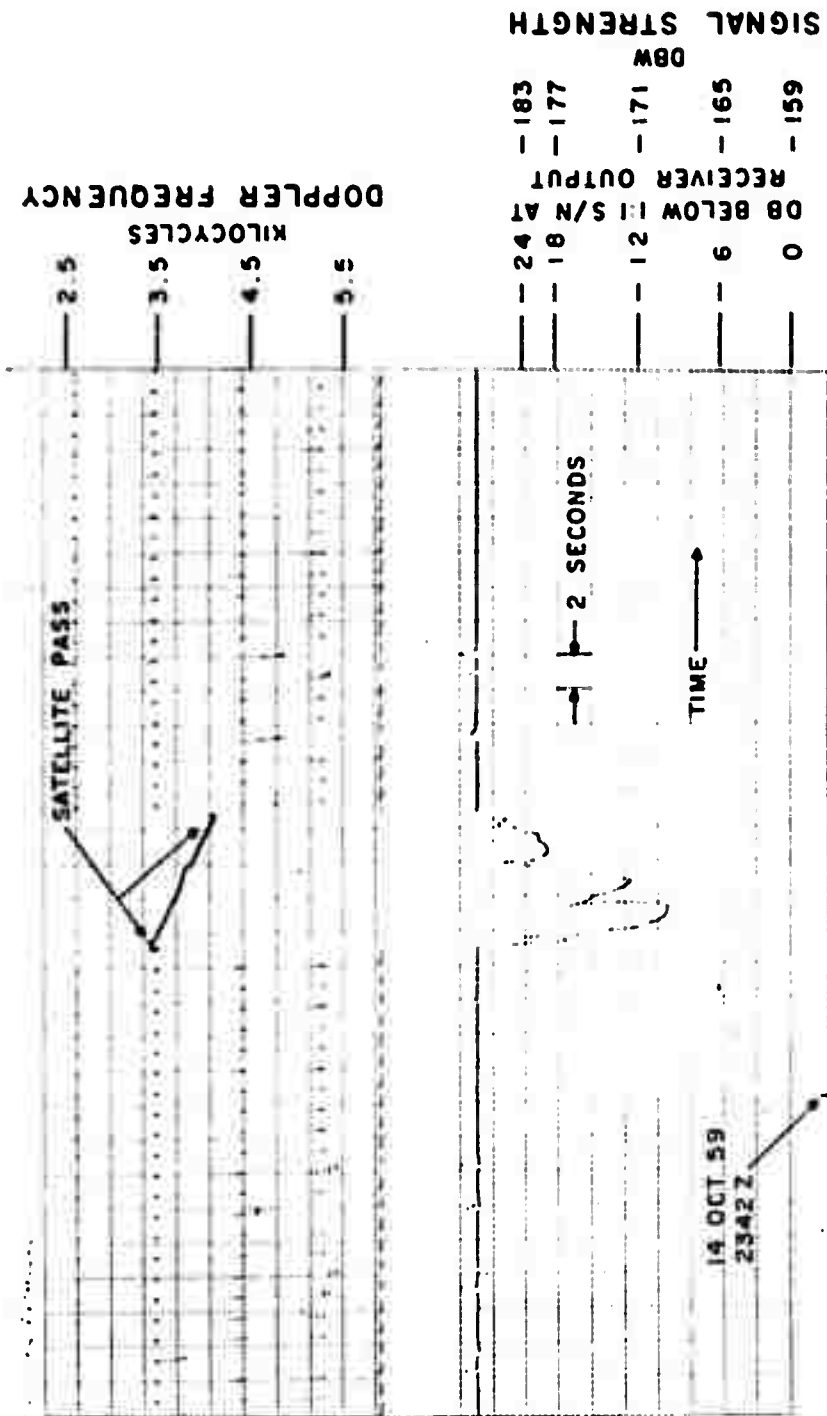
ARPA-BRL DOPLOC DOPPLER RECORD OF
59 ZETA REV. 871, FORREST CITY, ARKANSAS
MEASURED 2342:09 Z, PREDICTED 2345 Z
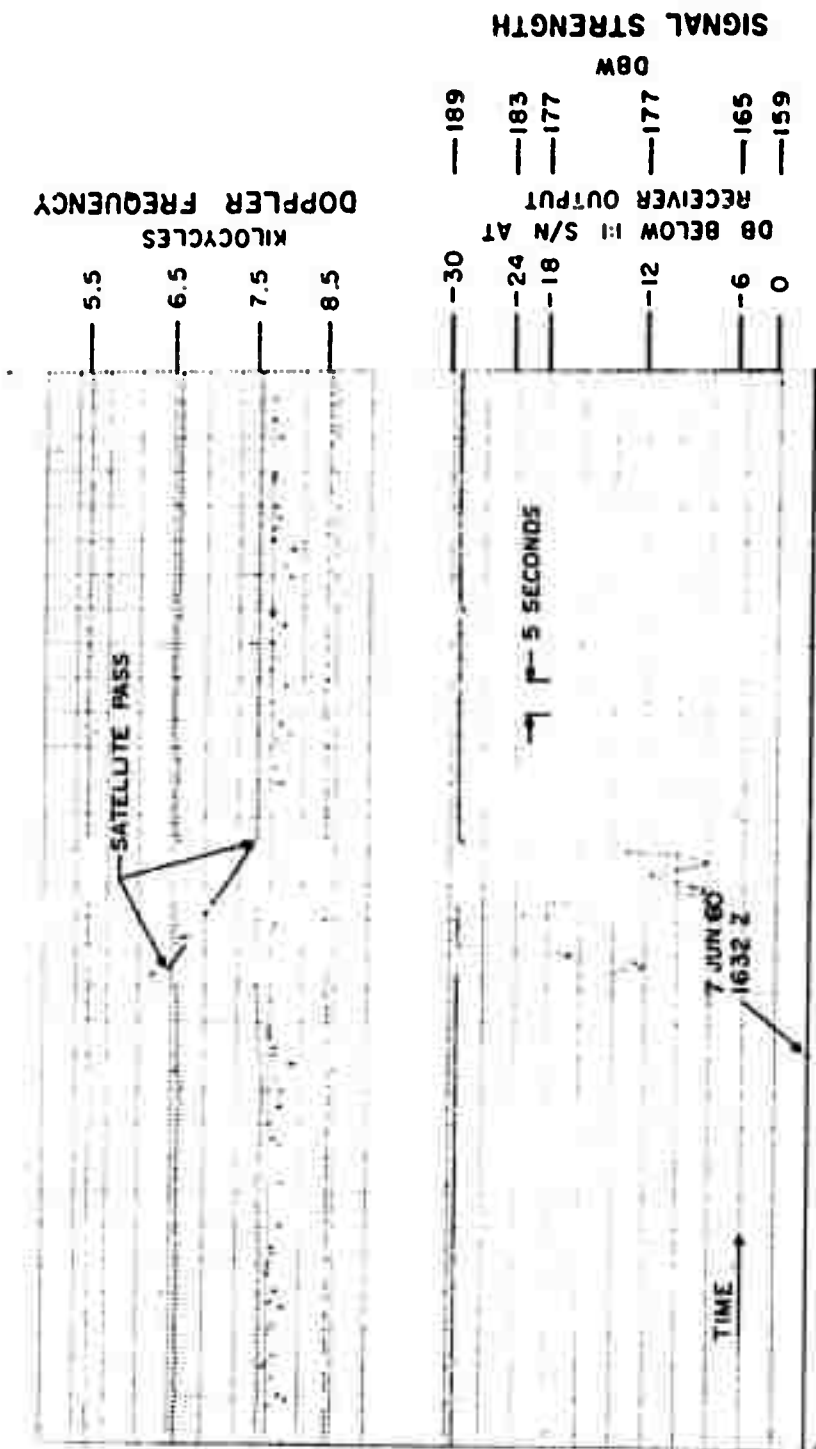ALTITUDE 175 MILES, 108 MILES EAST FT. SILL
CENTER ANTENNA, SOUTH-NORTH PASS

Fig. 58

DOPPLER FREQUENCY
KILOCYCLES

SIGNAL STRENGTH
DBW
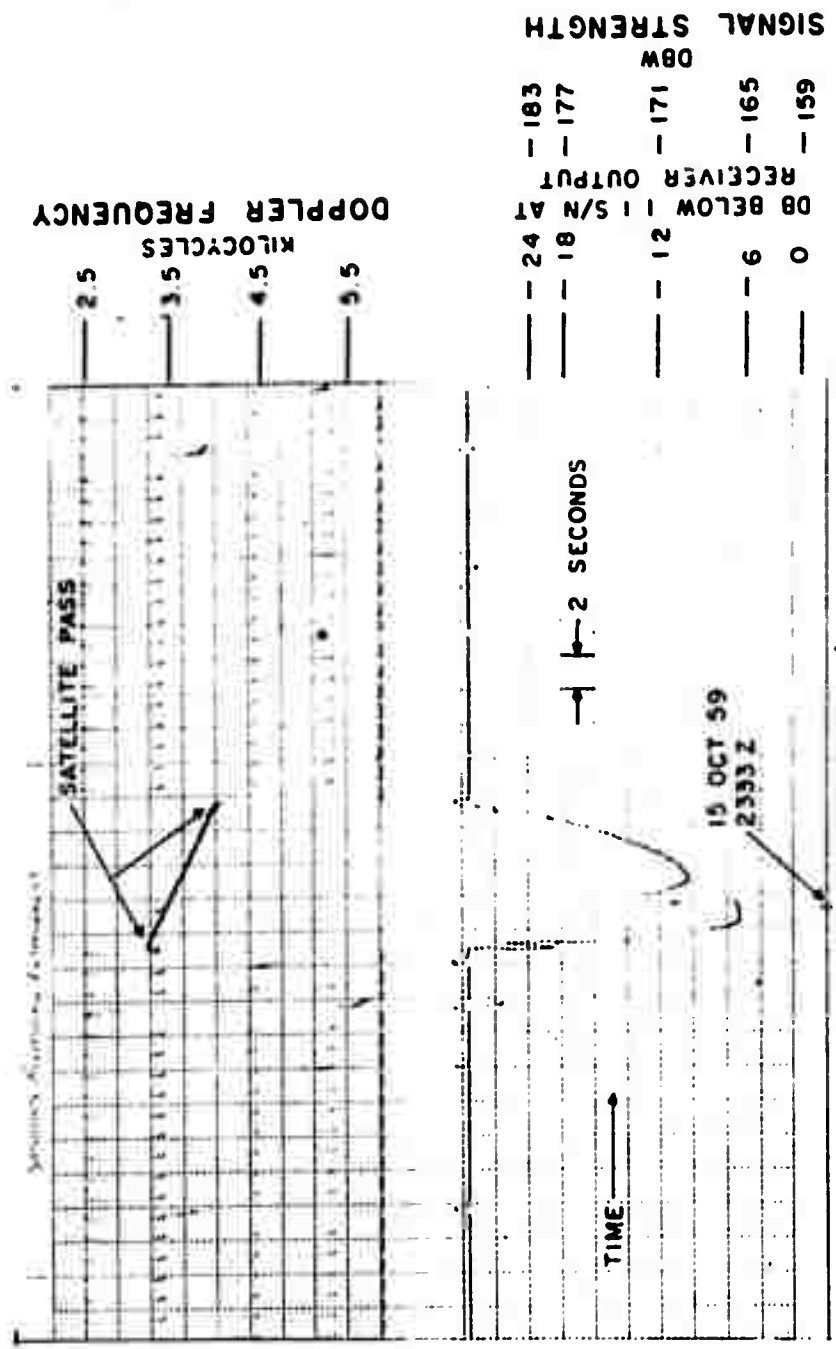
ARPA - BRL DOPLOC DOPPLER RECORD OF
59 ZETA REV. 887, FORREST CITY, ARKANSAS
MEASURED 2332:58 Z, PREDICTED 2338 Z
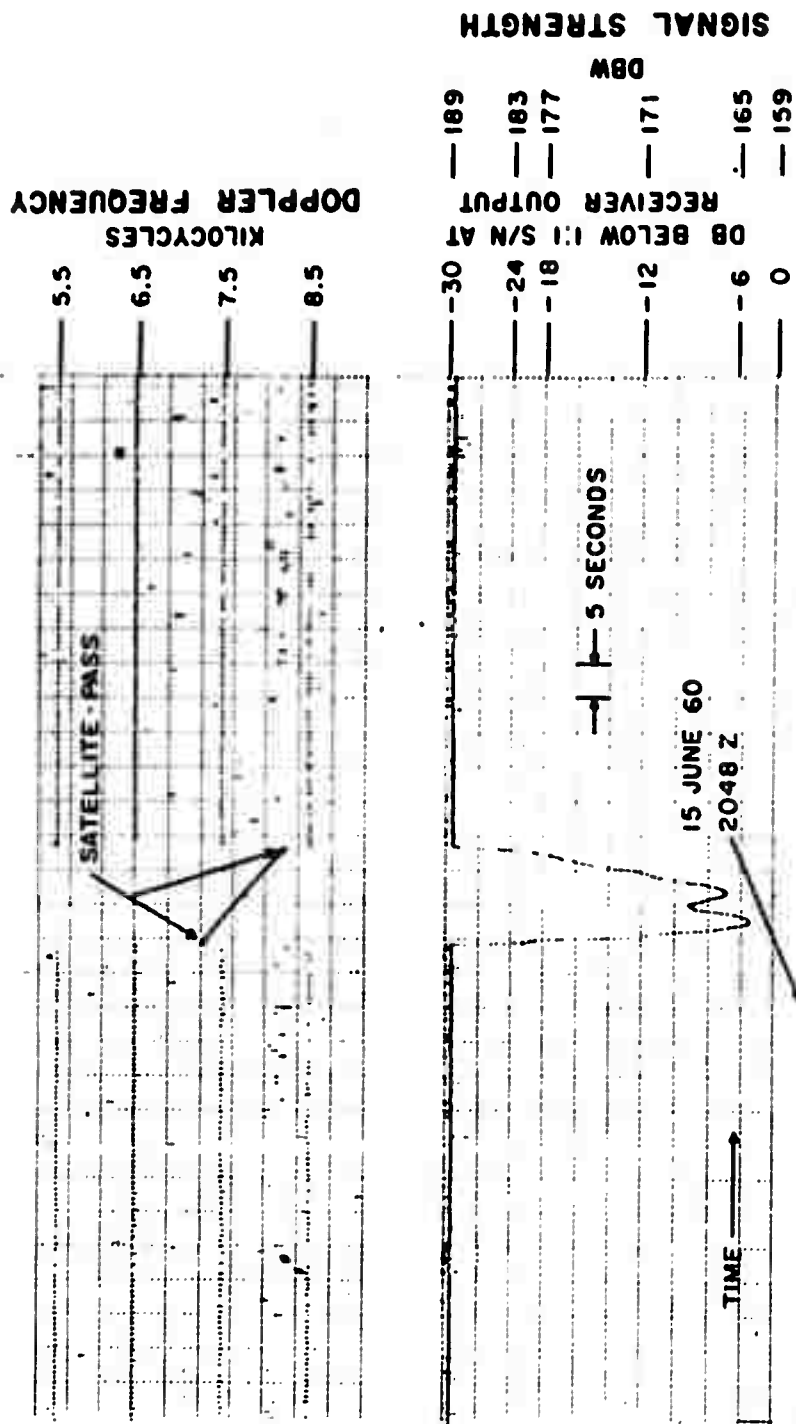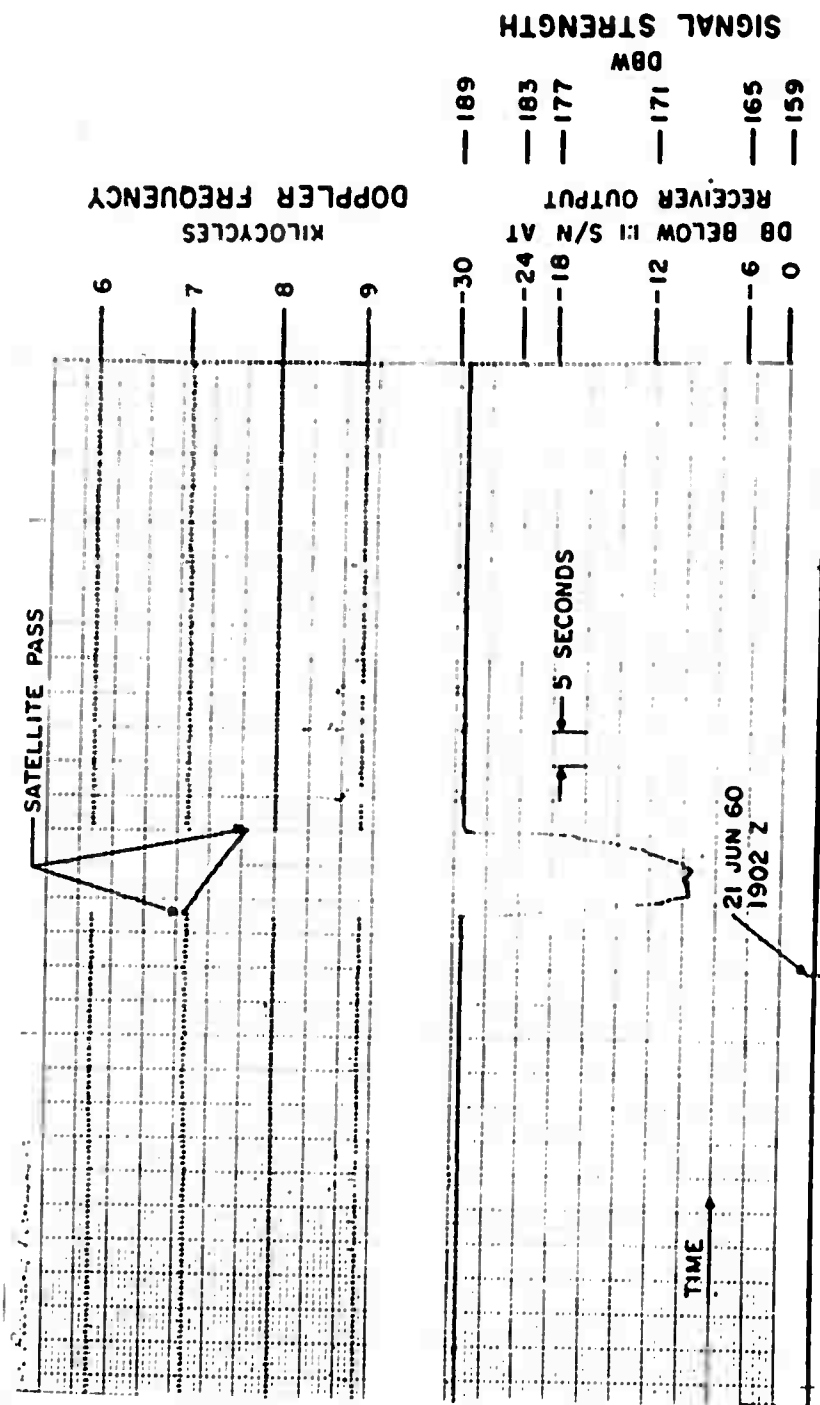ALTITUDE 170 MILES, 123 MILES EAST FT. SILL
CENTER ANTENNA, SOUTH—NORTH PASS

Fig. 59

115
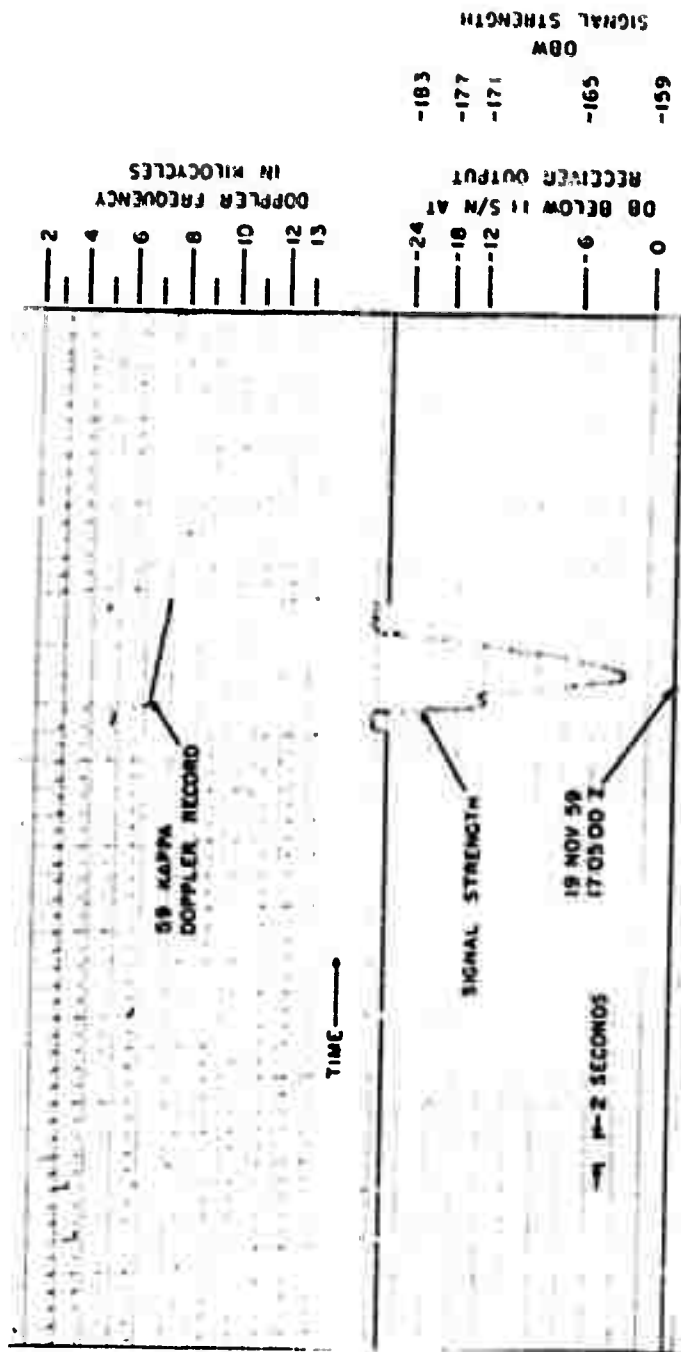
ARPA — BRL DOPLOC DOPPLER RECORD OF
59 KAPPA REV 183 FORREST CITY, ARKANSAS
MEASURED 17:04:58 Z, PREDICTED 17:06 Z
ALTITUDE 115 MILES, 314 MILES EAST FT SILL
CENTER ANTENNA, NORTH-SOUTH PASS

Fig. 60
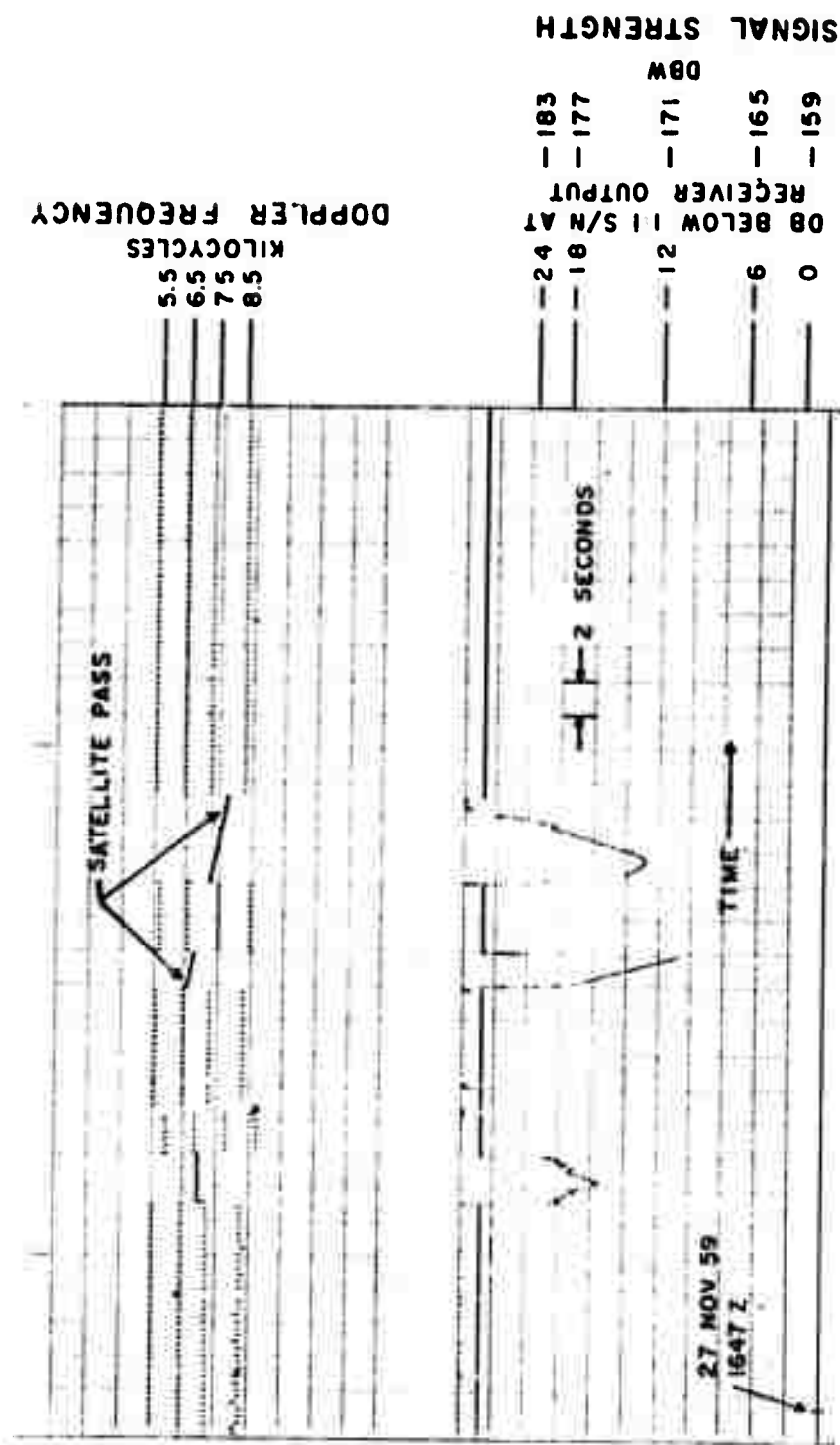
ARPA – BRL DOPLOC DOPPLER RECORD OF
59 LAMBDA REV. 96, FORREST CITY, ARKANSAS
MEASURED 1647:24 Z, PREDICTED 1639 Z
ALTITUDE 124 MILES, 323 MILES EAST FT. SILL
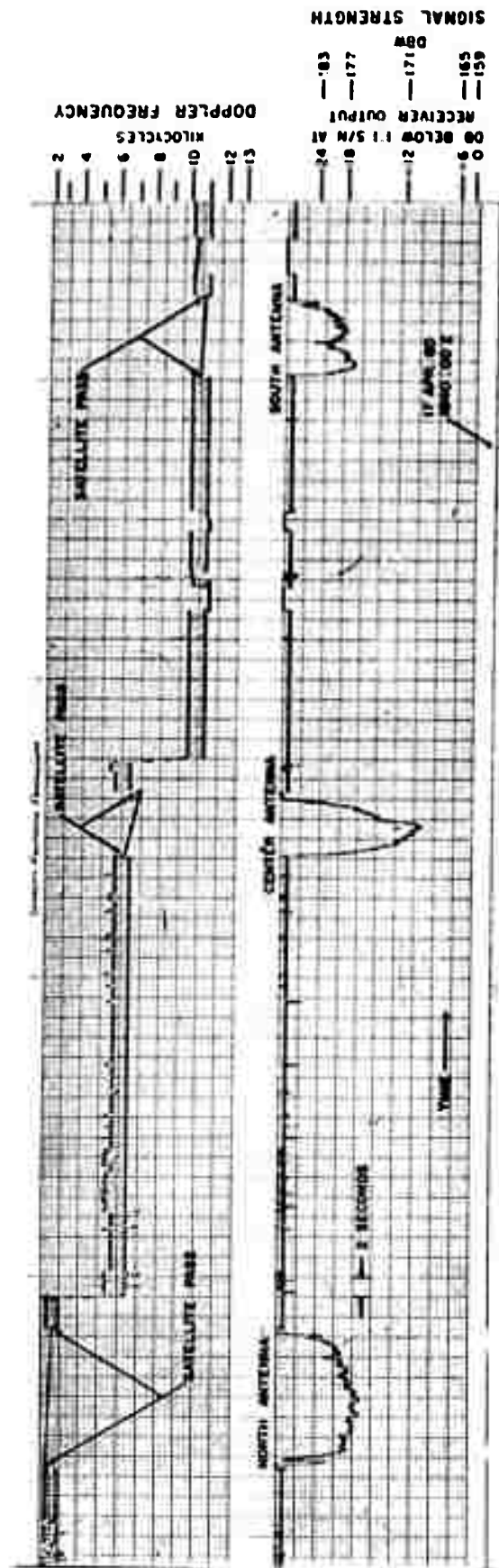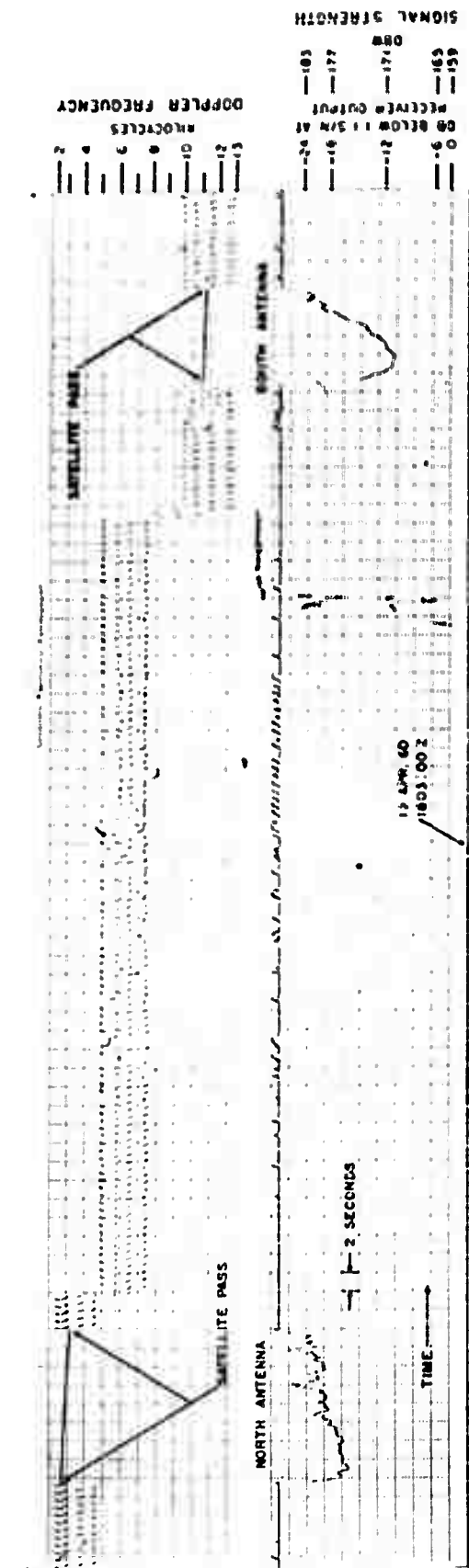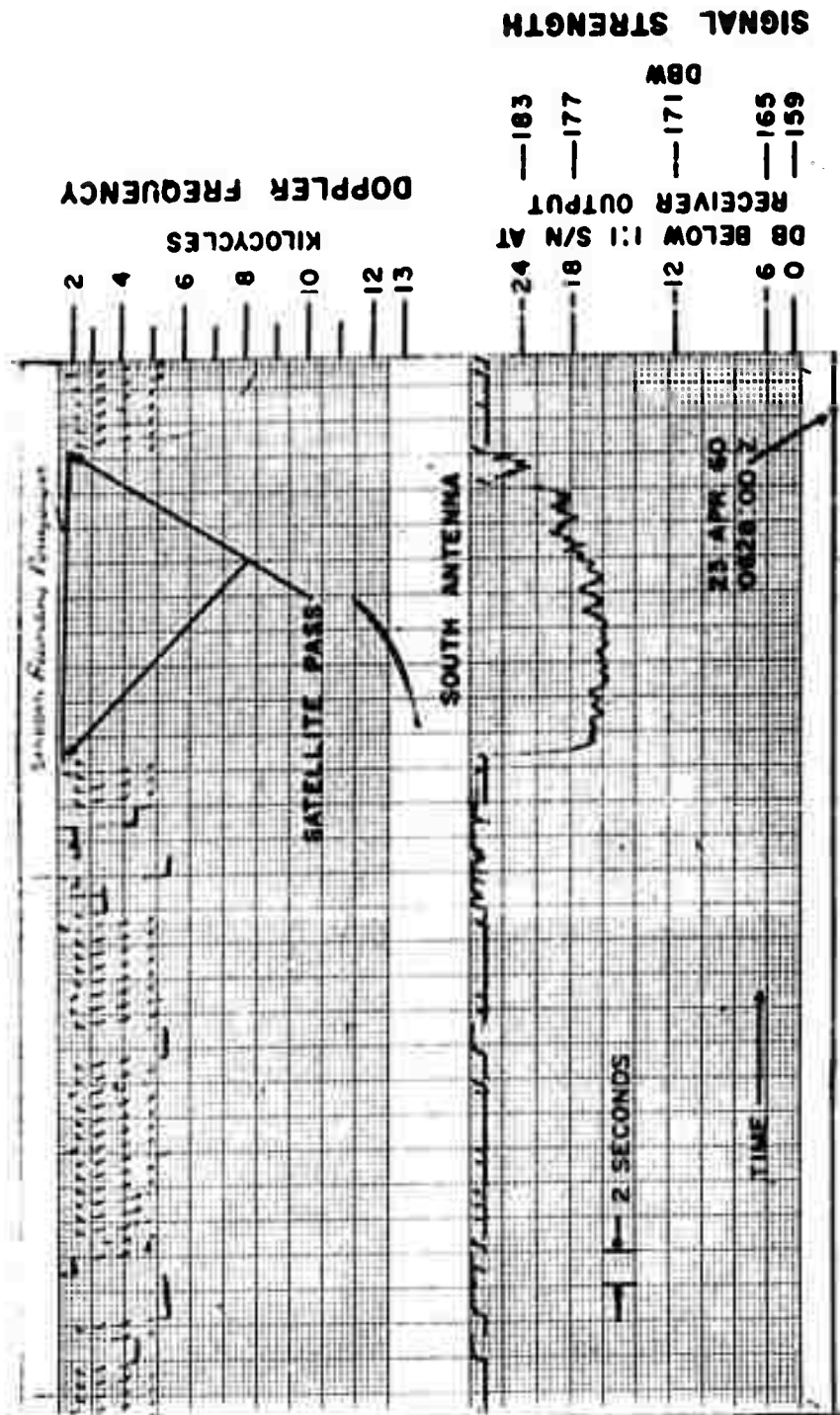CENTER ANTENNA, NORTH – SOUTH PASS

Fig. 61

DOPPLER FREQUENCY
IN KILOCYCLES

5.5 6.5 7.5 8.5

SIGNAL STRENGTH
IN DECIBELS BELOW
0.07 MICROVOLTS

-24 -18 -12 -9 -6 0

SATELLITE PASS

1-2 SECONDS

TIME

30 NOV 59
16:44:00 Z
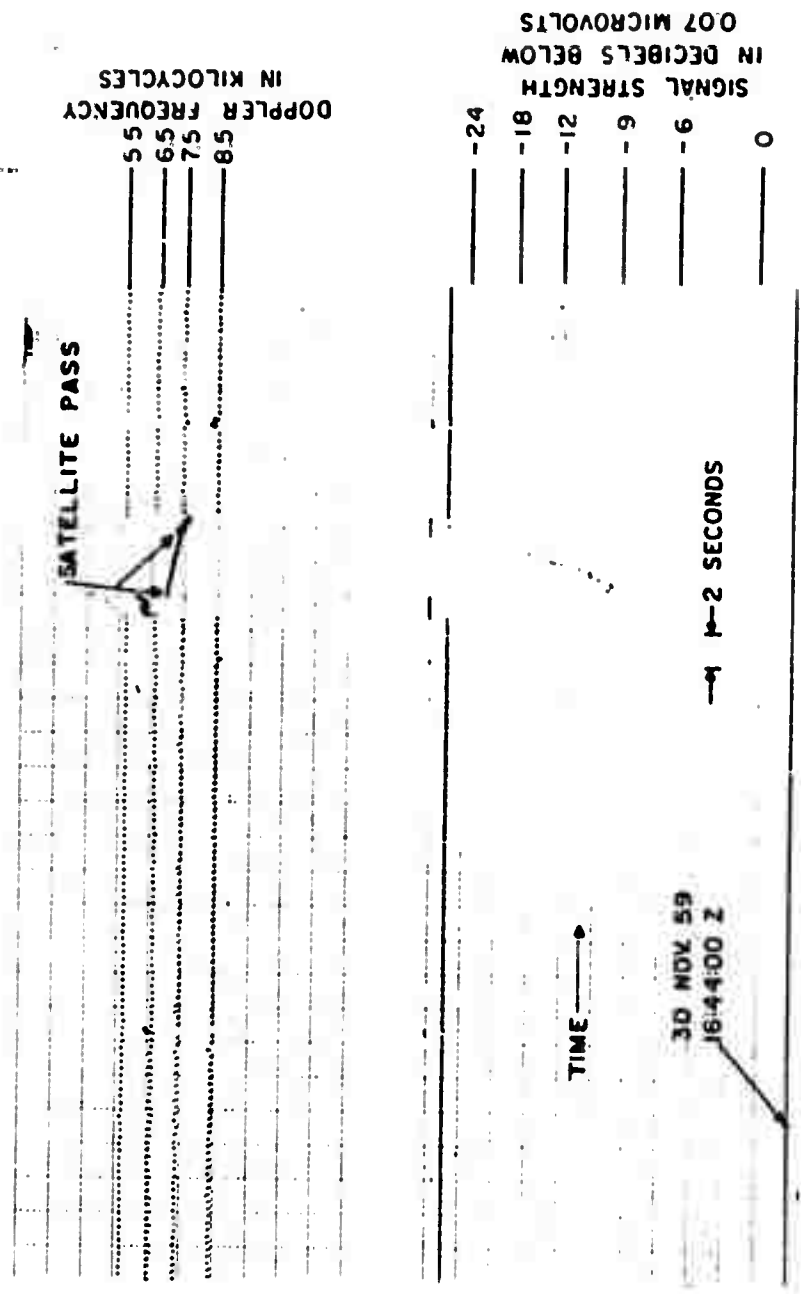
ARPA-BRL DOPLOC DOPPLER RECORD OF
59 LAMBDA REV 138 FORREST CITY, ARKANSAS
MEASURED 16:44:31 Z, PREDICTED 16:40 Z
ALTITUDE 138 MILES, OVERHEAD FT. SILL
CENTER ANTENNA, NORTH-SOUTH PASS

Fig. 62

118

ANALOG FREQUENCY
IN KILOCYCLES

SIGNAL STRENGTH
IN DECIBELS BELOW
.007 MICROVOLTS

SATELLITE PASS

SATELLITE PASS

CENTER ANTENNA

NORTH ANTENNA

2 SECONDS

15 05 00 Z

10 DEC 59
15 04 00 Z
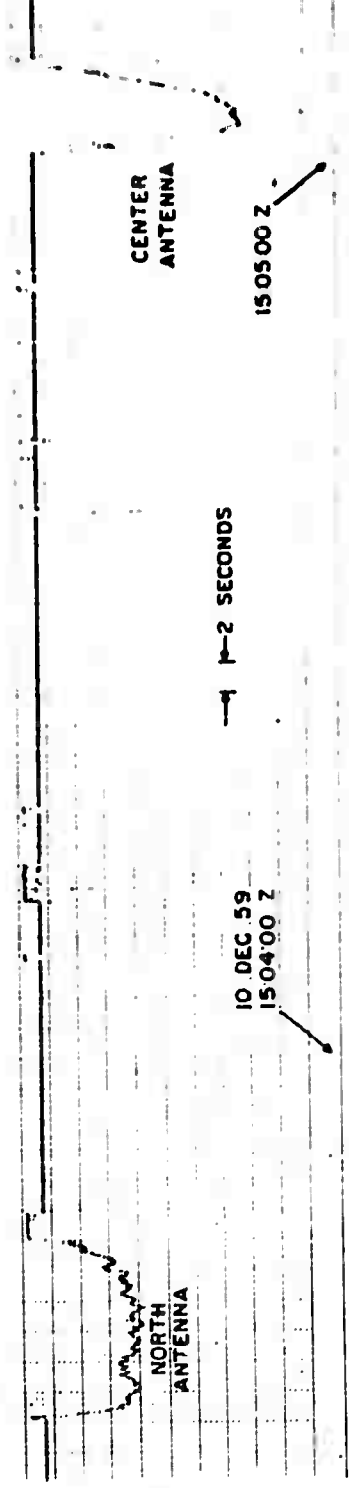
ARPA — BRL DOPLOC DOPPLER RECORD OF
59 LAMBDA REV 278 FORREST CITY, ARKANSAS
MEASURED 15:03:36 Z , PREDICTED 15:17 Z
ALTITUDE 218 MILES, 59 MILES EAST FORT SILL
NORTH AND CENTER ANTENNAS, N-S PASS

Fig. 63

119

ANALOG FREQUENCY
IN KILOCYCLES

SIGNAL STRENGTH
IN DECIBELS BELOW
0.07 MICROVOLTS

CENTER
ANTENNA

SOUTH
ANTENNA

2 SECONDS

8 JAN 60
0016:00 Z

0017:00 Z
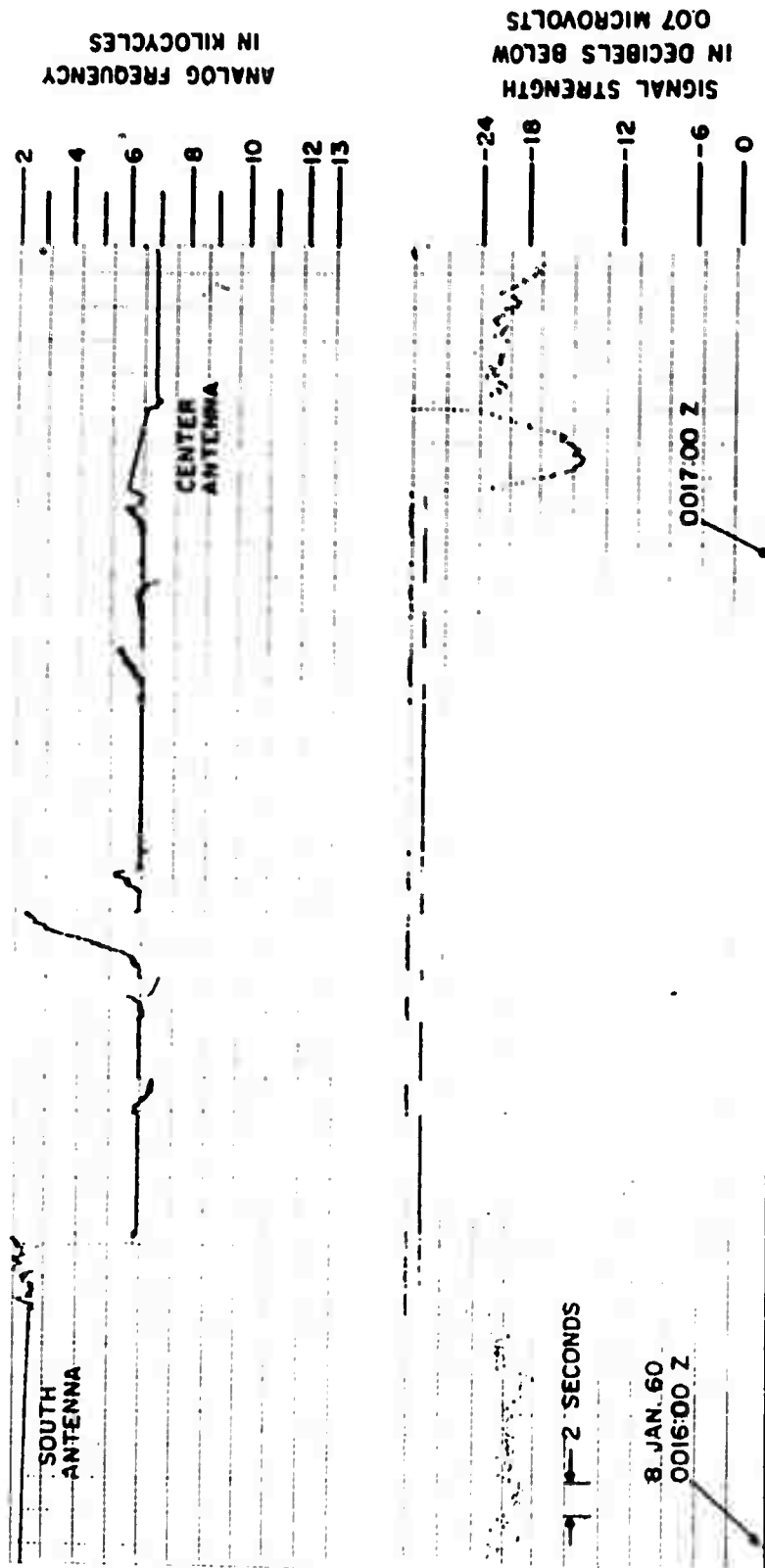
ARPA—BRL DOPLOC DOPPLER RECORD OF
59 LAMBDA REV. 685, FORREST CITY, ARKANSAS
MEASURED 0016:01 Z, PREDICTED 0020 Z
ALTITUDE 138 MILES , 26 MILES WEST FT. SILL
SOUTH AND CENTER ANTENNAS
SOUTH—NORTH PASS

Fig. 64

120

DOPPLER FREQUENCY
IN KILOCYCLES

SIGNAL STRENGTH
IN DECIBELS BELOW
0.07 MICROVOLTS

SATELLITE PASS

2 SECONDS

17 FEB 60
0514 Z

TIME
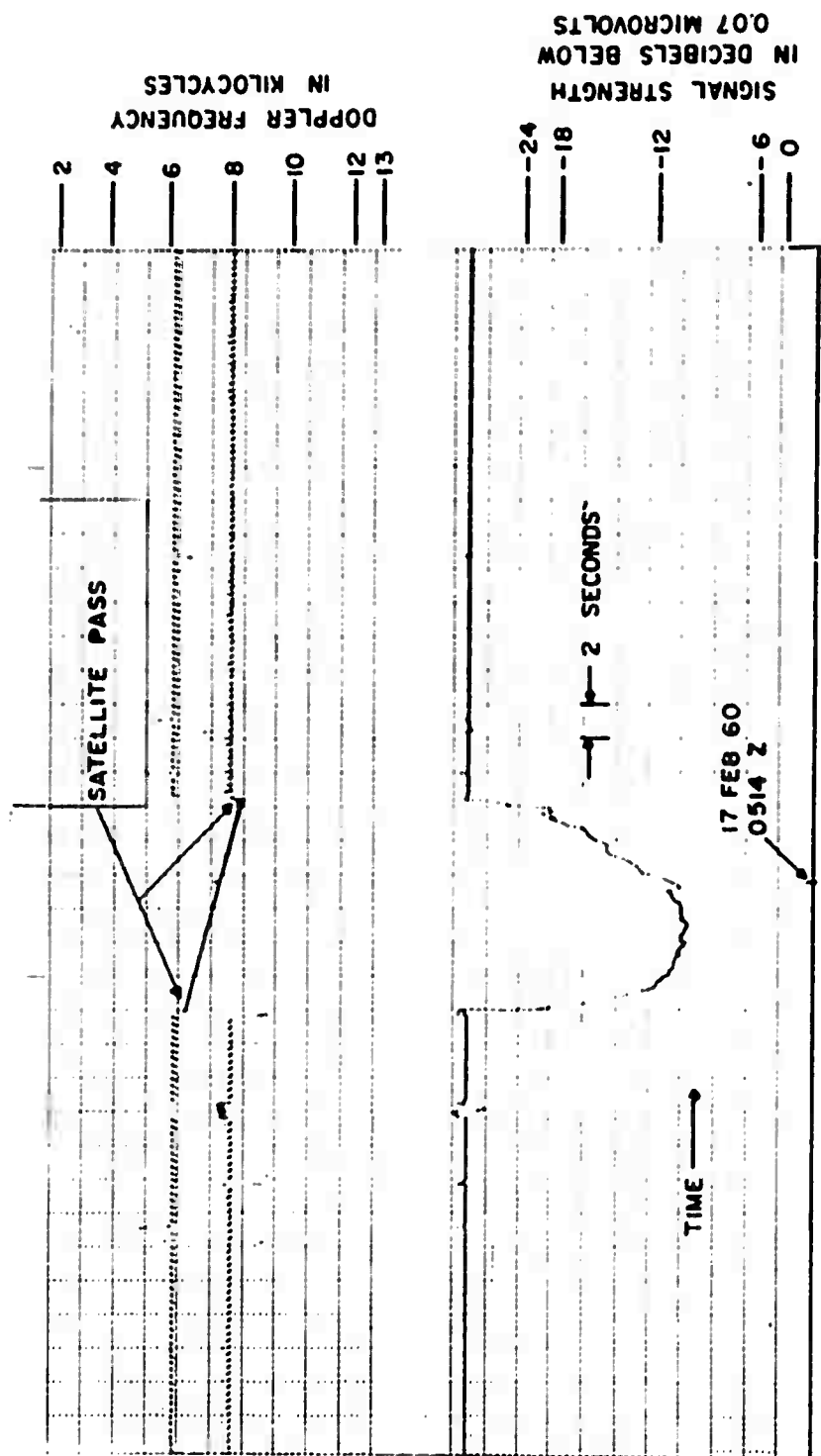
ARPA-BRL DOPLOC DOPPLER RECORD OF
59 LAMBDA REV. 1285 FORREST CITY, ARKANSAS
MEASURED 0513:53 Z, PREDICTED 0511 Z
ALTITUDE 356 MILES, 342 MILES EAST FT. SILL
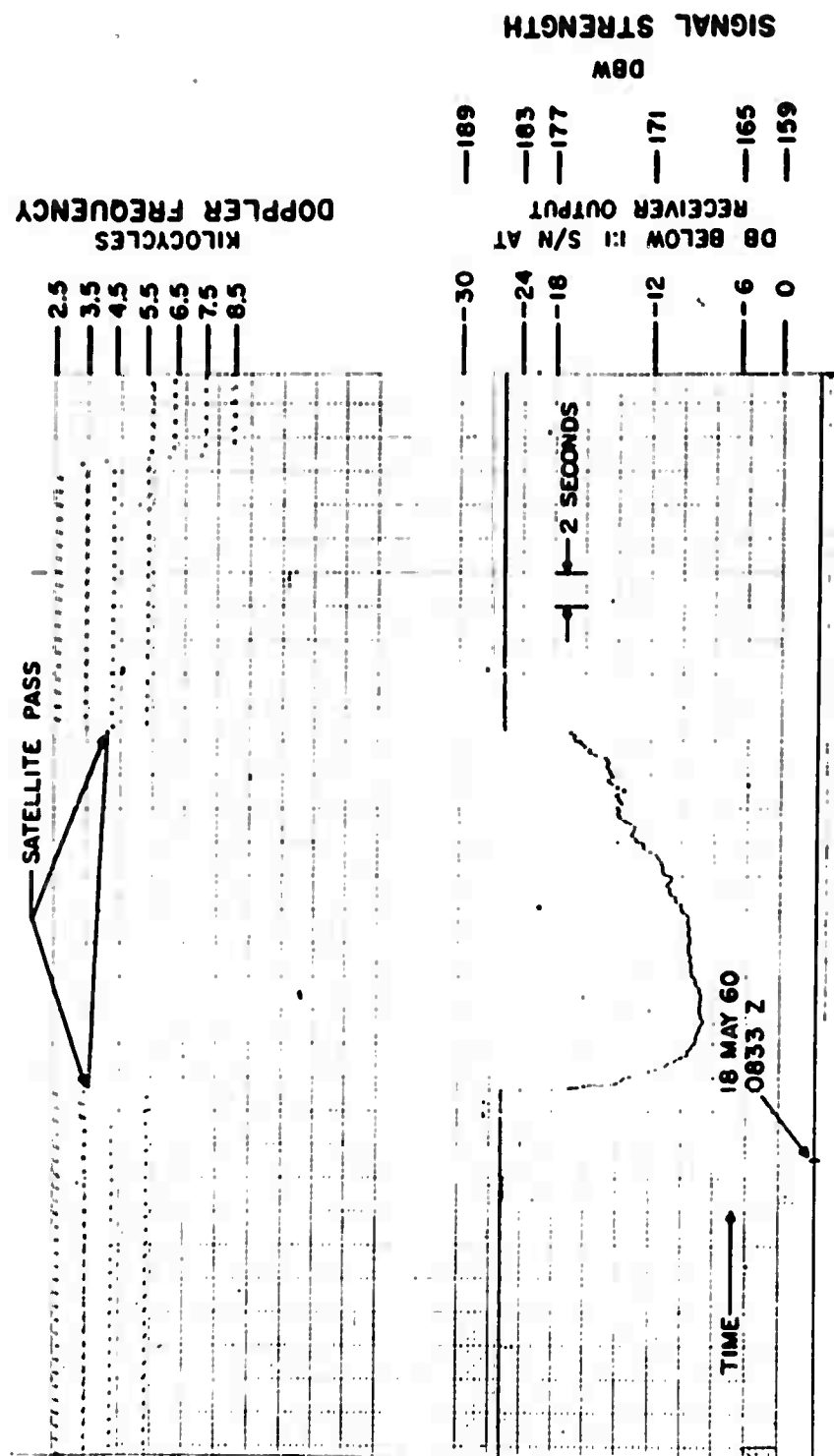CENTER ANTENNA, NORTH-SOUTH PASS

Fig. 65

ARPA – BRL DOPLOC DOPPLER RECORD OF
59 LAMBDA REV 1516, FORREST CITY, ARKANSAS
MEASURED 0256:10 Z, PREDICTED 0253 Z
ALTITUDE 137 MILES, 256 MILES EAST FT. SILL
CENTER ANTENNA, NORTH – SOUTH PASS

Fig. 66

ARPA - BRL DOPLOC DOPPLER RECORD OF
60 GAMMA I REV. 318, FORREST CITY, ARKANSAS
MEASURED 1257:23 Z, PREDICTED 1256 Z
ALTITUDE 440 MILES, 187 MILES EAST FT. SILL
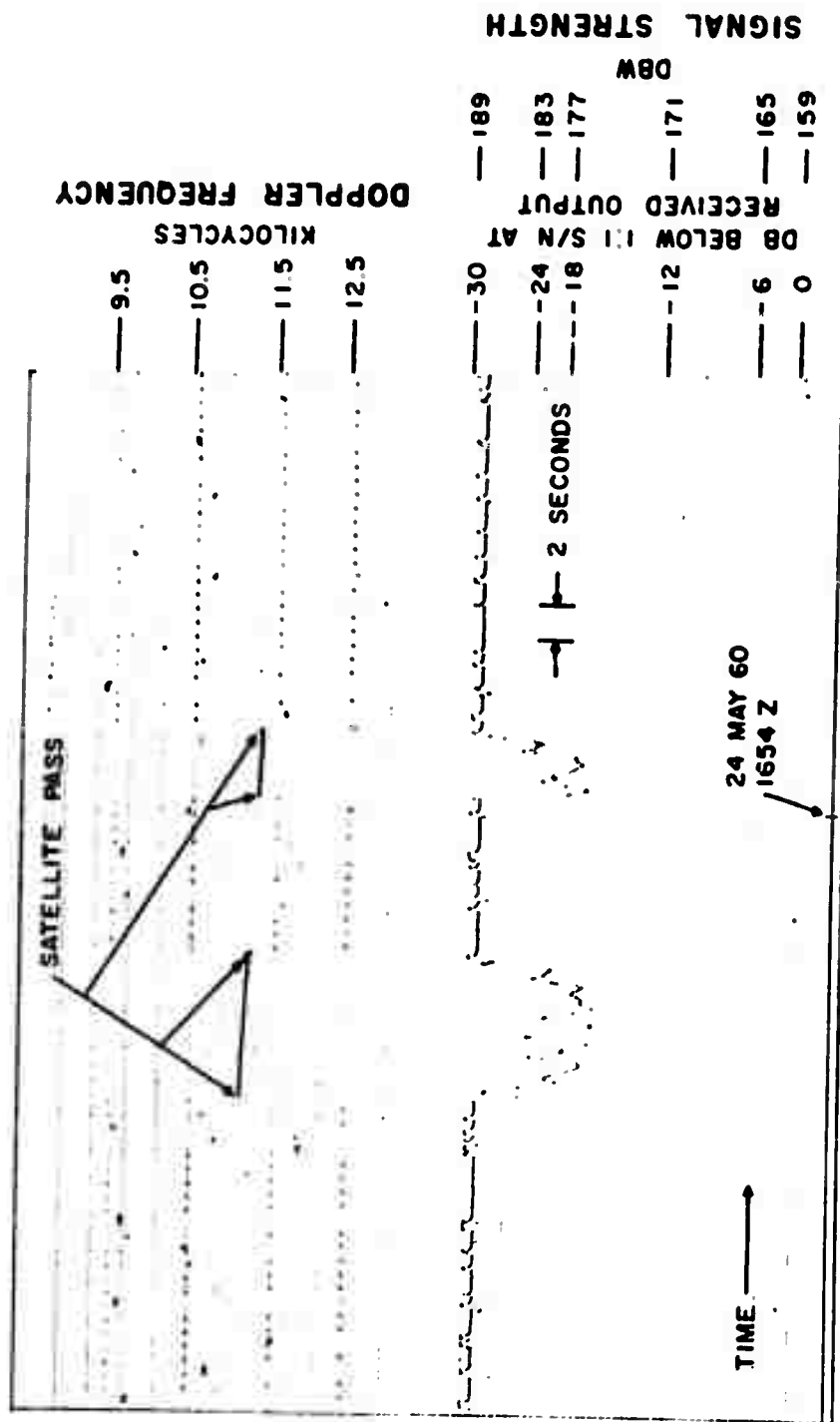CENTER ANTENNA, NORTH-SOUTH PASS

Fig. 67

SIGNAL STRENGTH
DBW

DOPPLER FREQUENCY
KILOCYCLES

RECEIVER OUTPUT
DB BELOW 1:1 S/N AT

SATELLITE PASS

5 SECONDS

10 MAY 60
0317 Z

TIME

ARPA — BRL DOPLOC DOPPLER RECORD OF
60 GAMMA I REV. 403, FORREST CITY, ARKANSAS
MEASURED 0317:28 Z, PREDICTED 0318 Z
ALTITUDE 271 MILES, 400 MILES EAST FT. SILL
CENTER ANTENNA, SOUTH—NORTH PASS

Fig. 68

124

SIGNAL STRENGTH
DBW

RECEIVER OUTPUT
DB BELOW 1:1 S/N AT

DOPPLER FREQUENCY
KILOCYCLES

SATELLITE PASS

5 SECONDS

TIME

II MAY 60
0303 Z

ARPA—BRL DOPLOC DOPPLER RECORD OF
60 GAMMA I REV. 418, FORREST CITY, ARKANSAS
MEASURED 0303:26 Z , PREDICTED 0304 Z
ALTITUDE 287 MILES , 212 EAST FT. SILL
CENTER ANTENNA , SOUTH—NORTH PASS

Fig. 69

125

SIGNAL STRENGTH

DBW

189
183
177
177
165
159

DOPPLER FREQUENCY
KILOCYCLES

DB BELOW 1:1 S/N AT
RECEIVER OUTPUT

5.5
6.5
7.5
8.5

-30
-24
-18
-12
-6
0

SATELLITE PASS

5 SECONDS

7 JUN 60
1632 Z

TIME

ARPA-BRL DOPLOC DOPPLER RECORD OF
60 GAMMA I REV. 836, FORREST CITY, ARKANSAS
MEASURED 1632:12 Z , PREDICTED 1633 Z
ALTITUDE 312 MILES , 232 MILES EAST FT. SILL
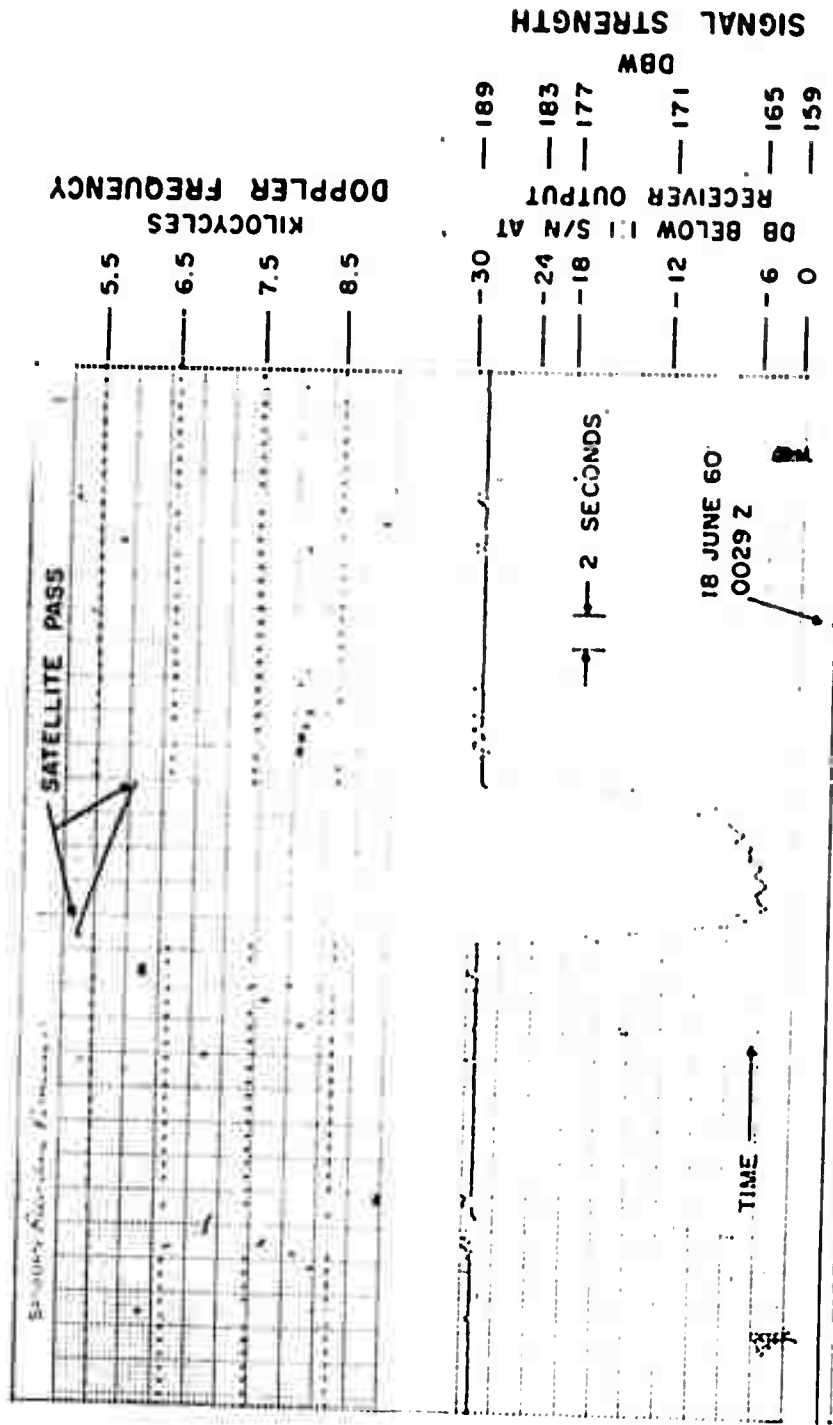CENTER ANTENNA , SOUTH– NORTH PASS

FIG. 70

126

SIGNAL STRENGTH
DBW

DOPPLER FREQUENCY
KILOCYCLES

RECEIVER OUTPUT
DB BELOW 1:1 S/N AT

SATELLITE - PASS

5 SECONDS

15 JUNE 60
2048 Z

TIME

ARPA - BRL DOPLOC DOPPLER RECORD OF
60 GAMMA I REV. 960, FORREST CITY, ARKANSAS
MEASURED 2048:10 Z, PREDICTED 2049 Z
ALTITUDE 205 MILES, 154 MILES EAST FT. SILL
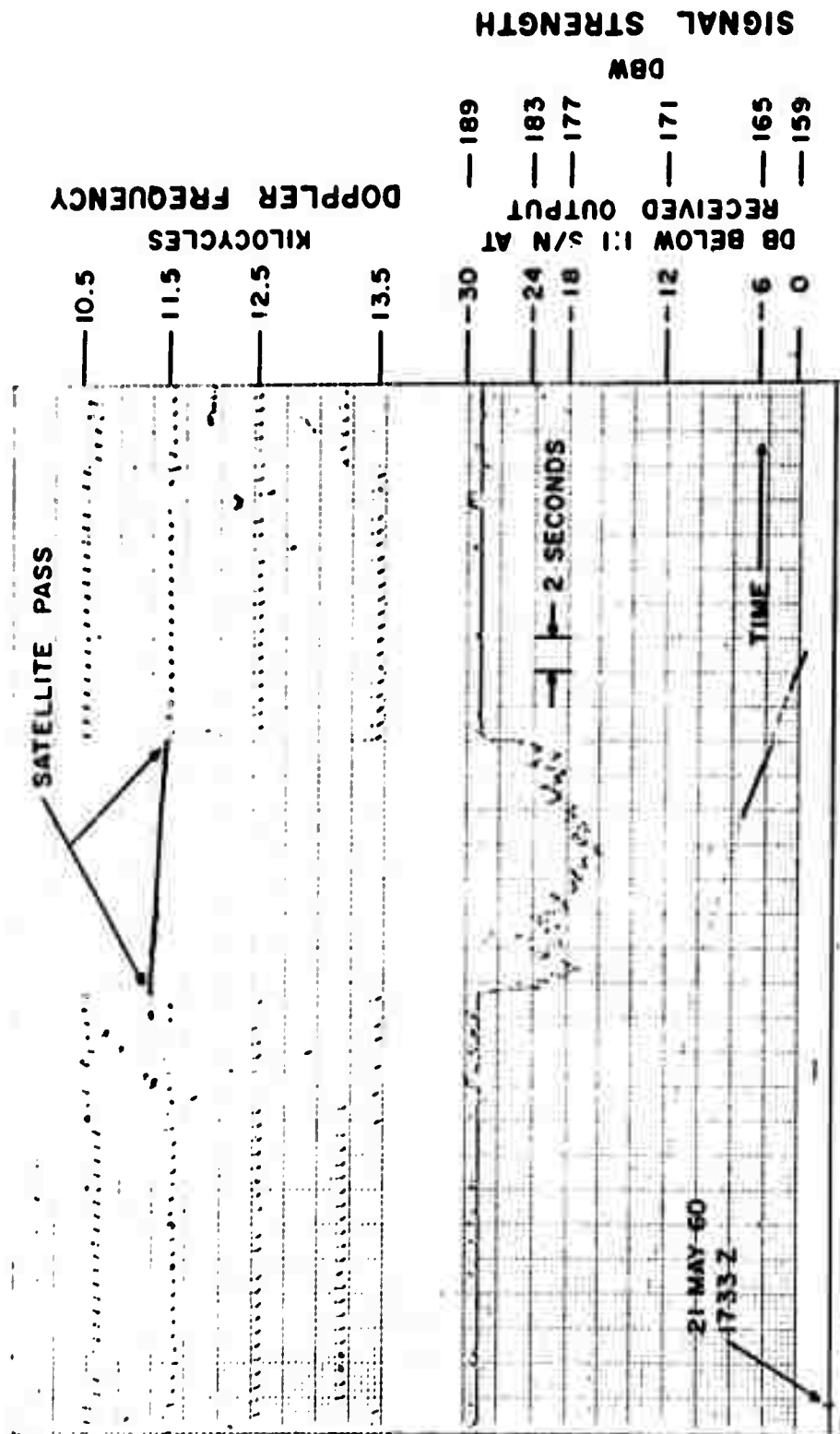CENTER ANTENNA, NORTH – SOUTH PASS

Fig. 71

127

SIGNAL STRENGTH
DBW

DOPPLER FREQUENCY
KILOCYCLES

RECEIVER OUTPUT
DB BELOW 1:1 S/N AT

SATELLITE PASS

5 SECONDS

21 JUN 60
1902 Z

TIME

ARPA — BRL DOPLOC DOPPLER RECORD OF
60 GAMMA 2 REV. 1042, FORREST CITY, ARKANSAS
MEASURED 1902:09 Z , PREDICTED 1900 Z
ALTITUDE 250 MILES , 235 MILES EAST FT. SILL
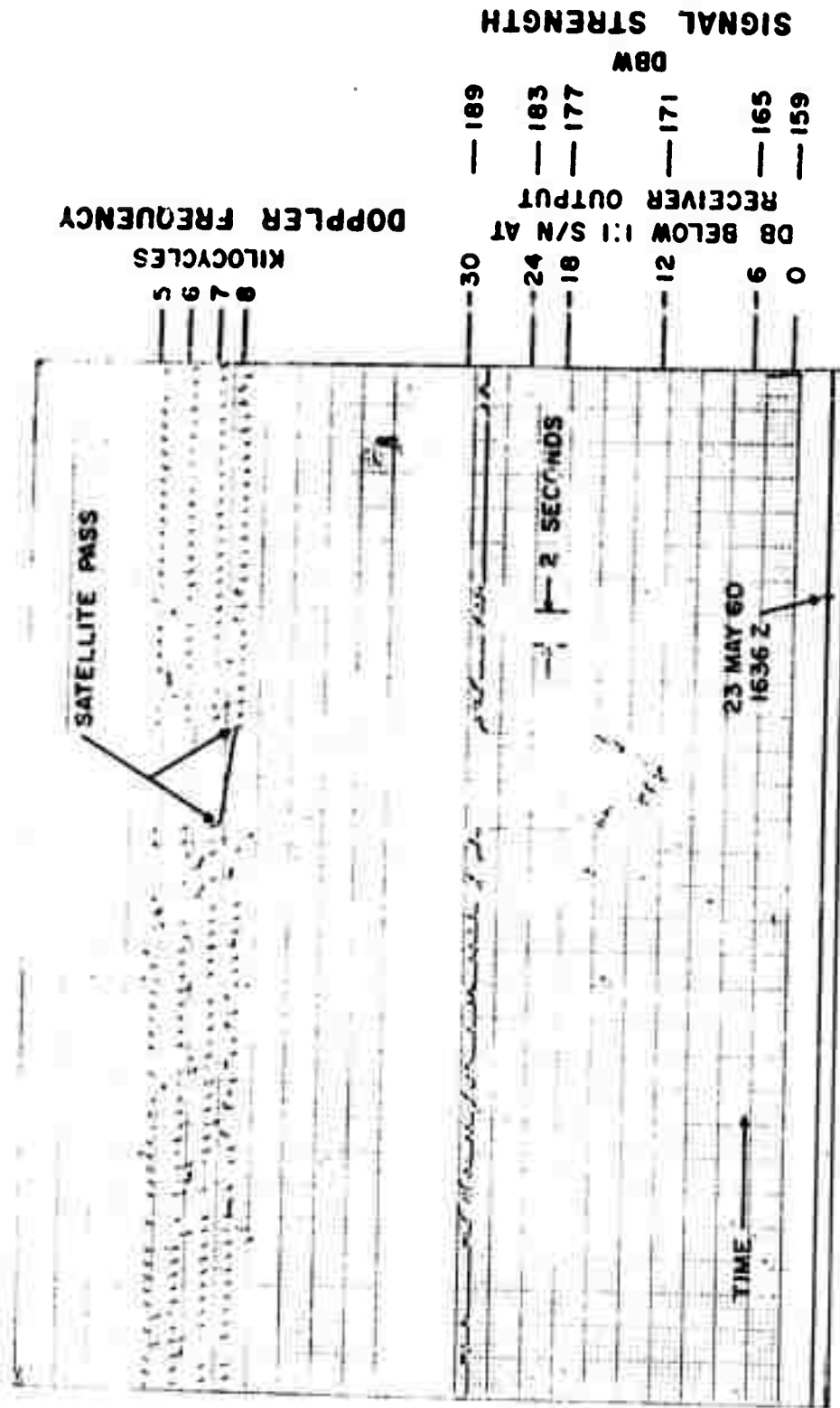CENTER ANTENNA, NORTH — SOUTH PASS

Fig. 72

128

ARPA - BRL DOPLOC DOPPLER RECORD OF
60 DELTA REV. 30, FORREST CITY, ARKANSAS
MEASURED 1839:19 Z, PREDICTED 1839:19 Z
ALTITUDE 111 MILES, 72 MILES EAST FT SILL
NORTH - CENTER - SOUTH ANTENNAS, NORTH - SOUTH PASS

Fig. 73

ARPA – BRL DOPLOC DOPPLER RECORD OF
60 DELTA REV 61, FORREST CITY, ARKANSAS
MEASURED 1802:50 Z, PREDICTED 1802 Z
ALTITUDE 111 MILES, 200 MILES EAST FT SILL
NORTH – SOUTH ANTENNAS, NORTH - SOUTH PASS

Fig. 74

ARPA - BRL DOPLOC DOPPLER RECORD OF
60 DELTA REV. 117, FORREST CITY, ARKANSAS
MEASURED 0627:41 Z, PREDICTED 0629 Z
ALTITUDE 204 MILES, 255 MILES EAST FT. SILL
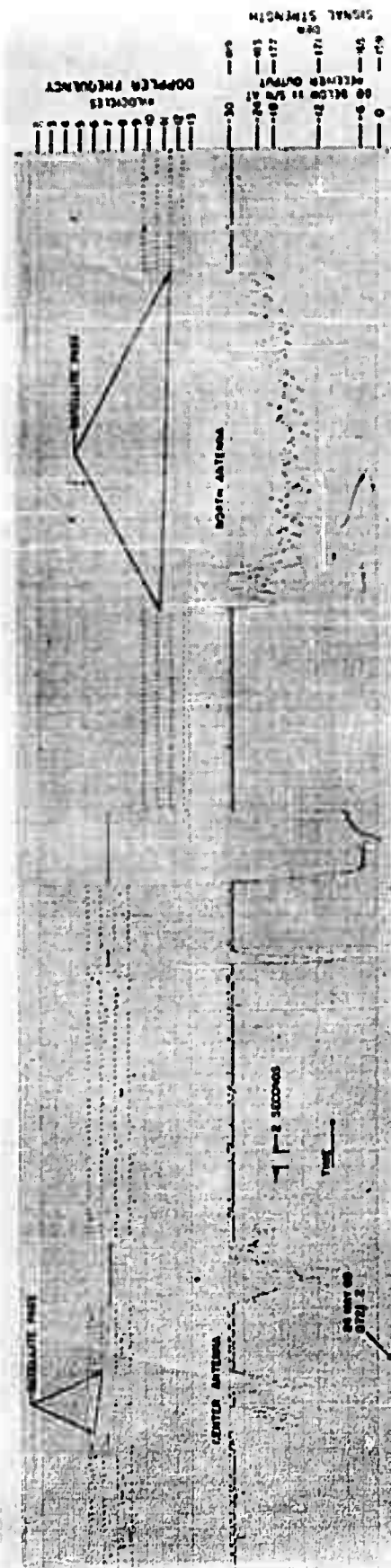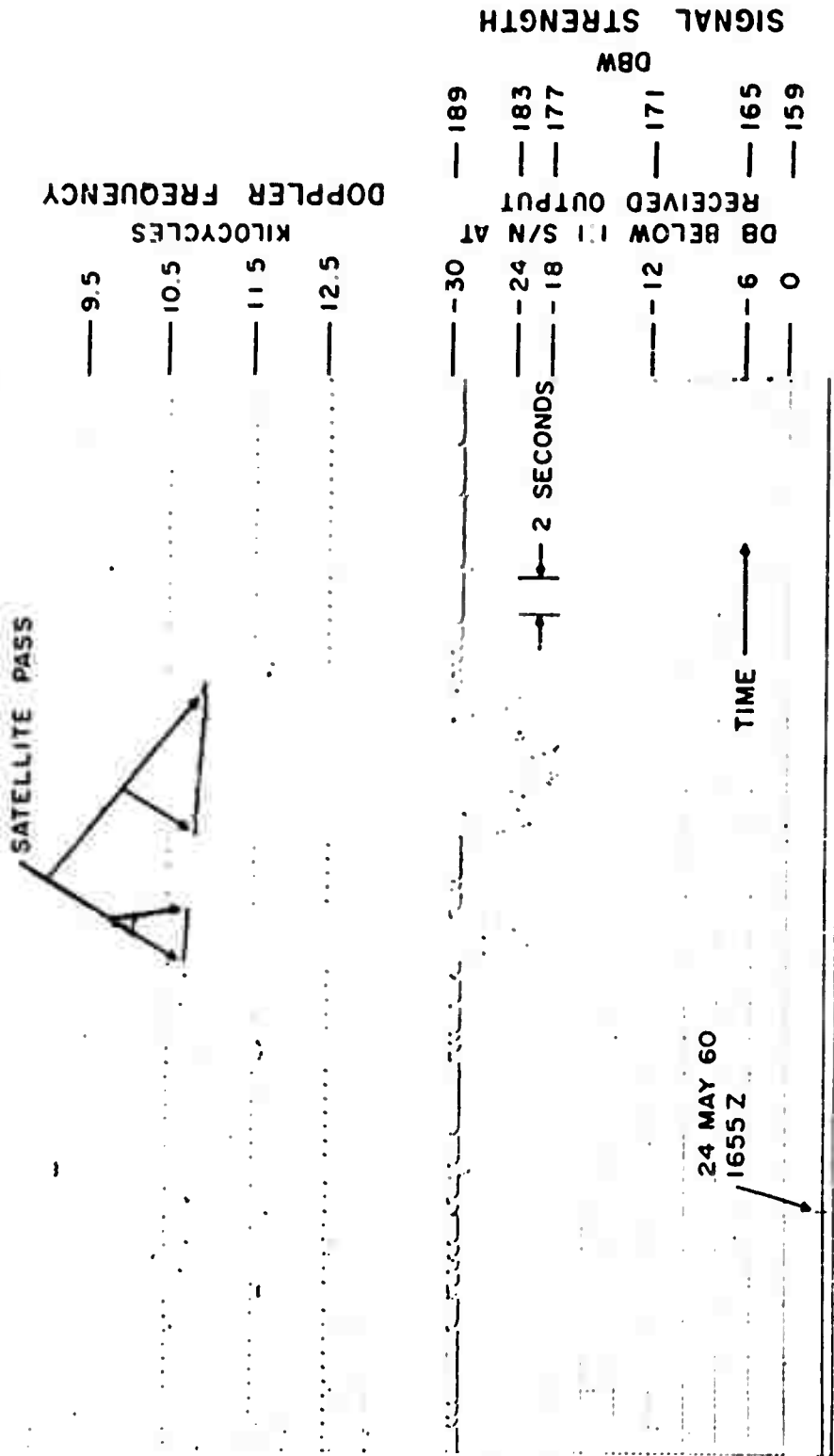SOUTH ANTENNA, SOUTH – NORTH PASS

Fig. 75

ARPA - BRL DOPLOC DOPPLER RECORD OF
60 DELTA REV. 124, FORREST CITY, ARKANSAS
MEASURED 1728-18 Z. PREDICTED 1728 Z
ALTITUDE 120 MILES, 320 MILES EAST FT SILL
NORTH - CENTER - SOUTH ANTENNAS, NORTH - SOUTH PASS

FIG. 76
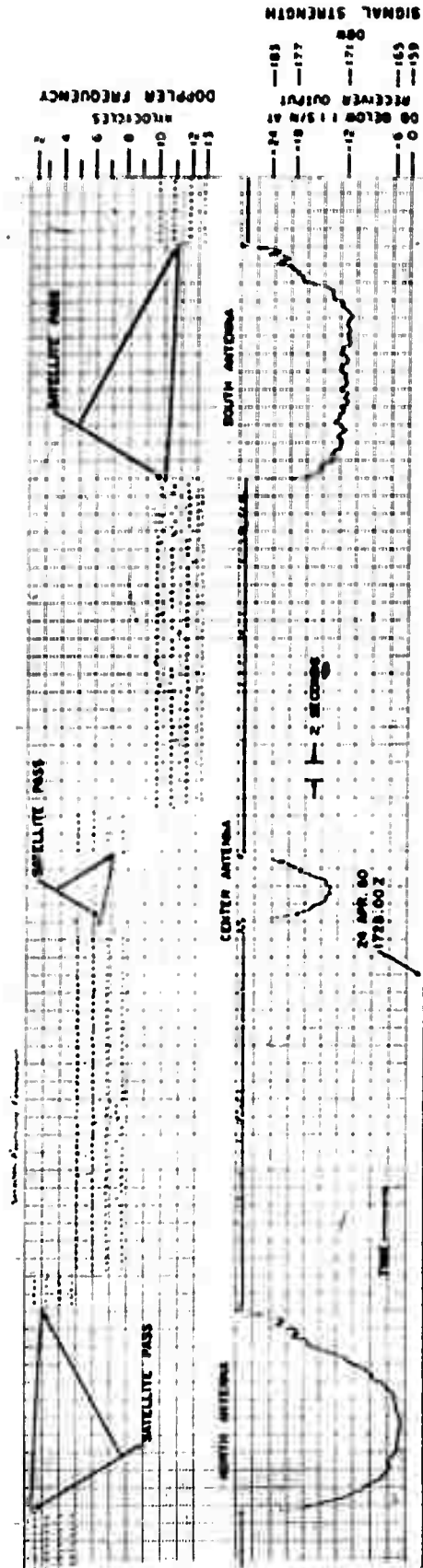
ARPA – BRL DOPLOC DOPPLER RECORD OF
60 DELTA REV 140, FORREST CITY, ARKANSAS
MEASURED 1728:06 Z, PREDICTED 1732 Z
ALTITUDE 116 MILES, 320 MILES EAST FT. SILL
NORTH – CENTER – SOUTH ANTENNAS, NORTH – SOUTH PASS

Fig. 77

DOPPLER FREQUENCY

KILOCYCLES

SIGNAL STRENGTH

DBM

RECEIVER OUTPUT

DB BELOW 1:1 S/N AT

NORTH ANTENNA

CENTER ANTENNA

SOUTH ANTENNA

SATELLITE PASS

SATELLITE PASS
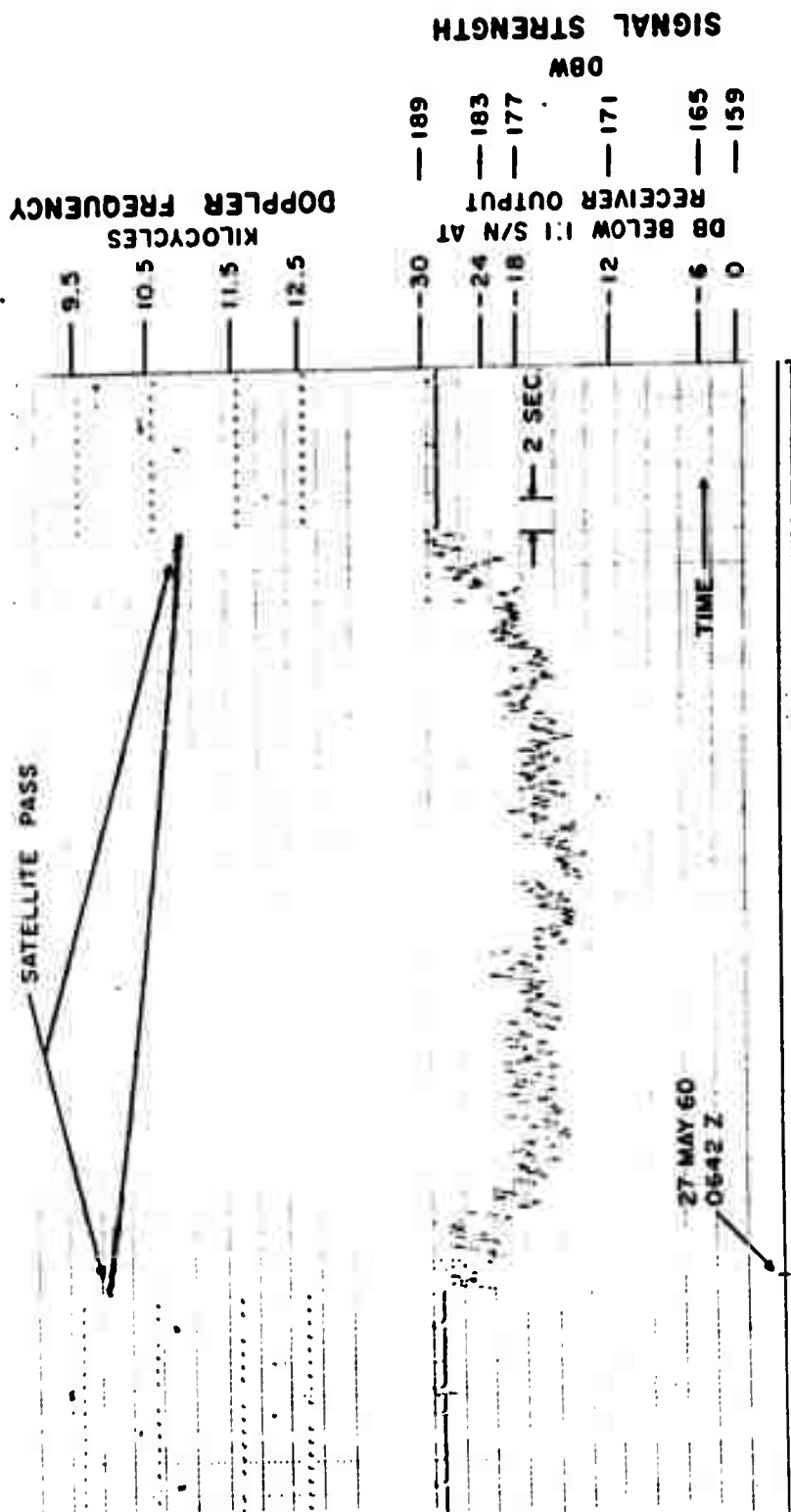
SATELLITE PASS

SATELLITE PASS

2 SECONDS

TIME

26 APR 60
1718:00 Z
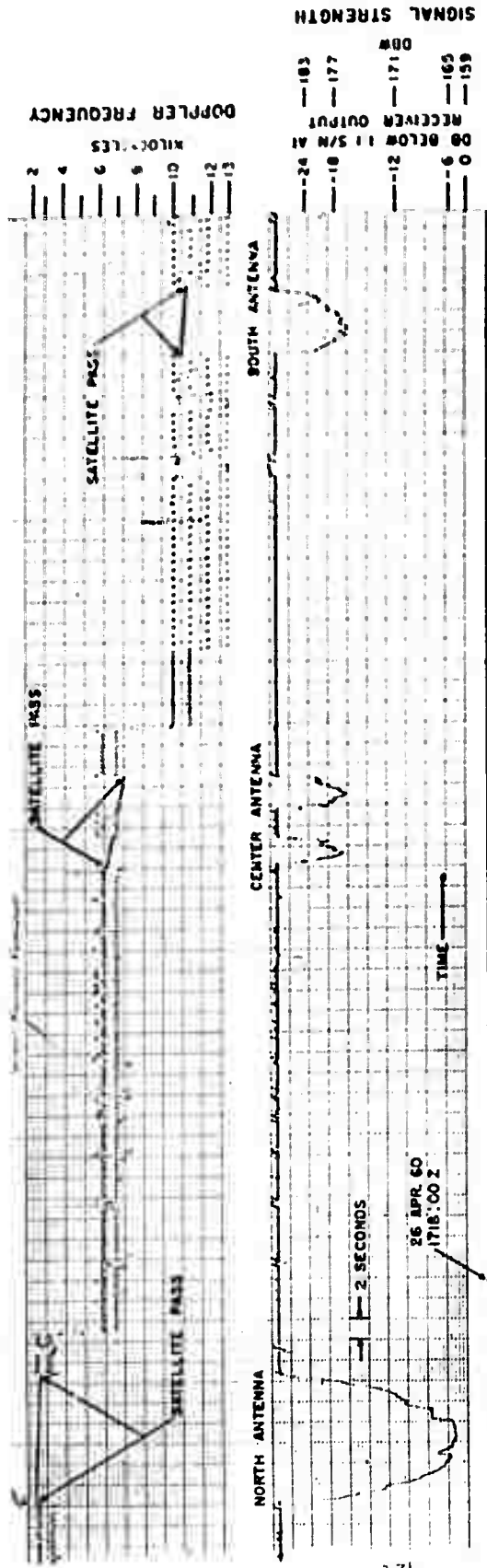
ARPA - BRL DOPLOC DOPPLER RECORD OF
60 DELTA REV. 156, FORREST CITY, ARKANSAS
MEASURED 1718:40 Z, PREDICTED 1725 Z
ALTITUDE 112 MILES, 143 MILES EAST FT. SILL
NORTH – CENTER – SOUTH ANTENNAS, NORTH – SOUTH PASS

Fig. 78

134

ARPA — BRL DOPLOC DOPPLER RECORD OF
60 DELTA REV. 169, FORREST CITY, ARKANSAS
MEASURED 0611 13 Z, PREDICTED 0615 Z
ALTITUDE 142 MILES, 90 MILES EAST FT. SILL
SOUTH — CENTER — NORTH ANTENNAS, SOUTH — NORTH PASS

Fig. 79

135

DOPPLER FREQUENCY
KILOCYCLES
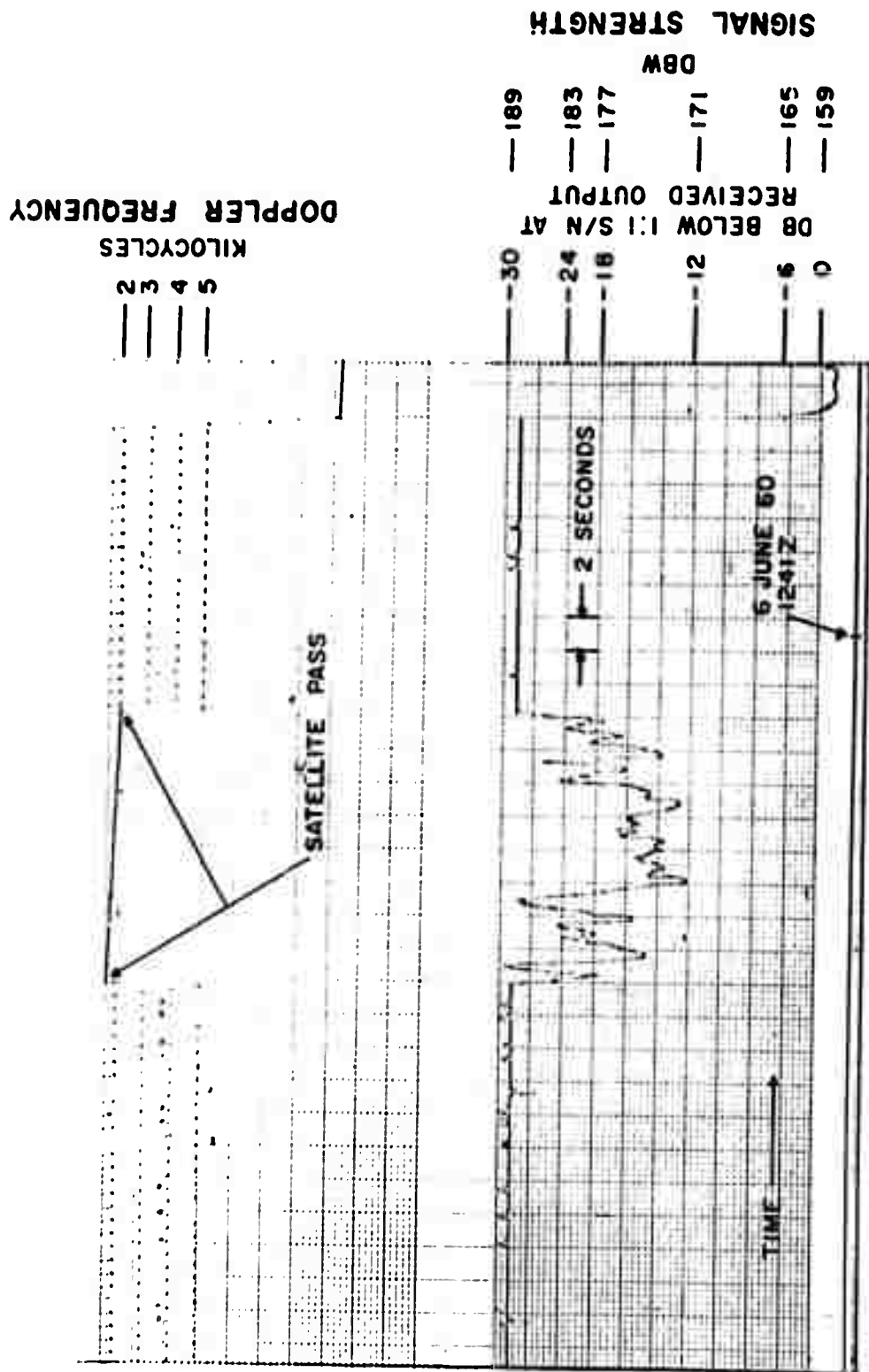
SIGNAL STRENGTH
DBW

RECEIVER OUTPUT
DB BELOW 1:1 S/N AT

ARPA – BRL DOPLOC DOPPLER RECORD OF
60 DELTA REV. 172, FORREST CITY, ARKANSAS
MEASURED 1653:56 Z, PREDICTED 1702 Z
ALTITUDE 77 MILES, 370 MILES EAST FT. SILL
NORTH – CENTER – SOUTH ANTENNAS, NORTH – SOUTH PASS

SOUTH ANTENNA

CENTER ANTENNA

NORTH ANTENNA

26 APR 60
1654:00 Z

2 SECONDS

TIME

136

FIG. 80

SIGNAL STRENGTH
DBW

DOPPLER FREQUENCY
KILOCYCLES

RECEIVER OUTPUT
DB BELOW 1:1 S/N AT
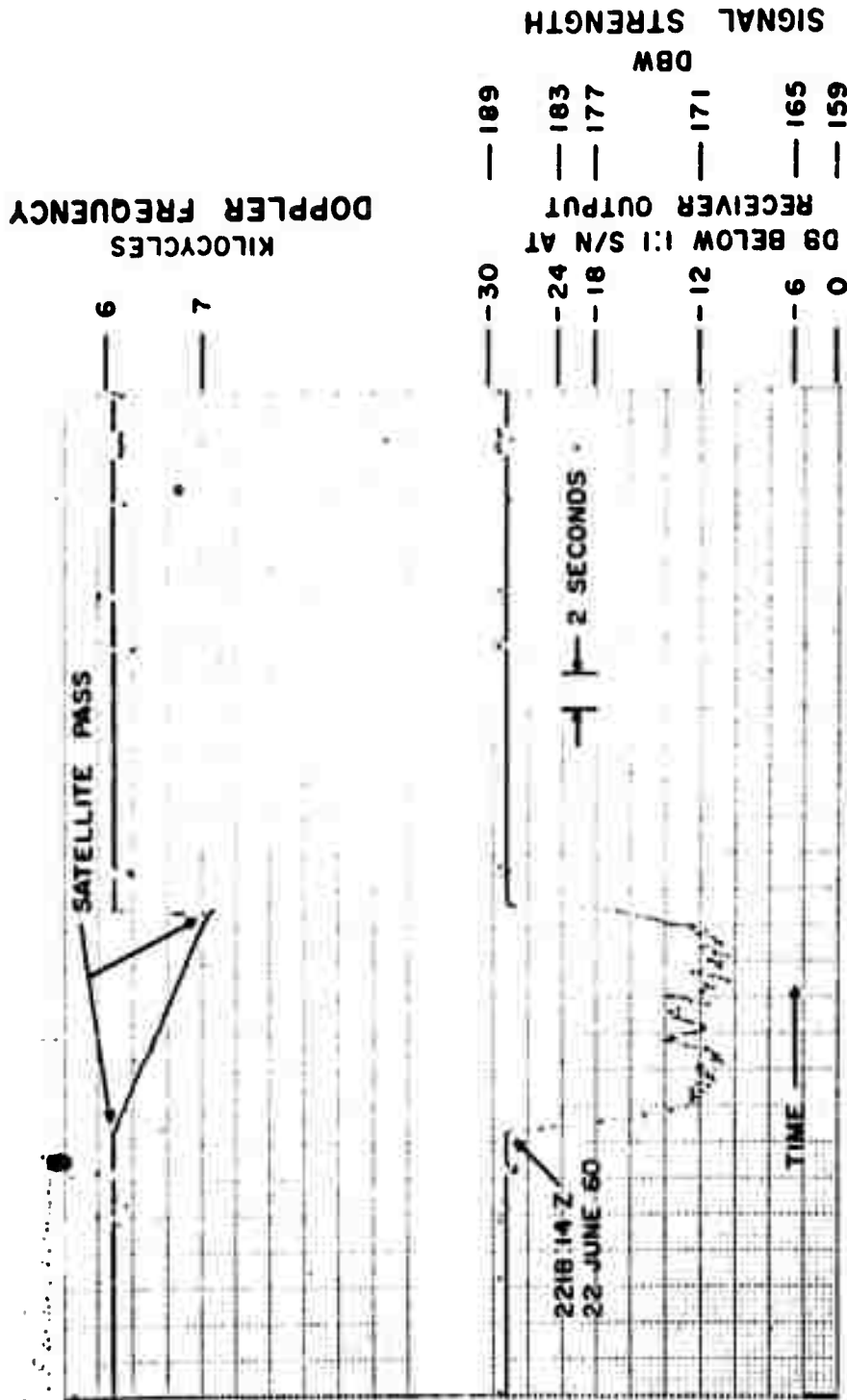
SATELLITE PASS

2 SECONDS

18 MAY 60
0833 Z

TIME

ARPA—BRL DOPLOC DOPPLER RECORD OF
60 EPSILON I REV. 53, FORREST CITY, ARKANSAS

MEASURED 0833:05 Z, PREDICTED 0833 Z
ALTITUDE 194 MILES, 252 MILES EAST FT SILL
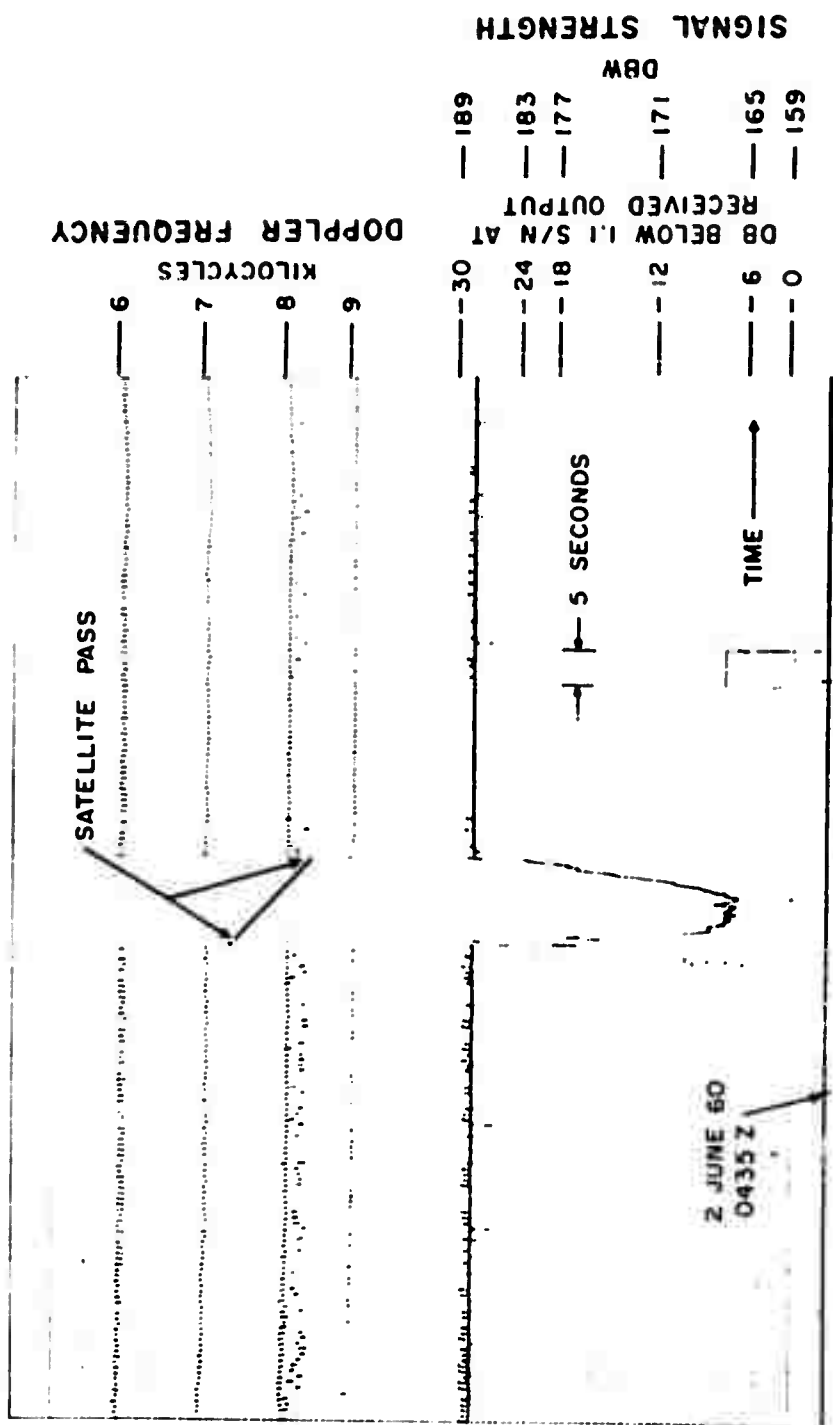SOUTH ANTENNA, SOUTH—NORTH PASS

Fig. 81

137
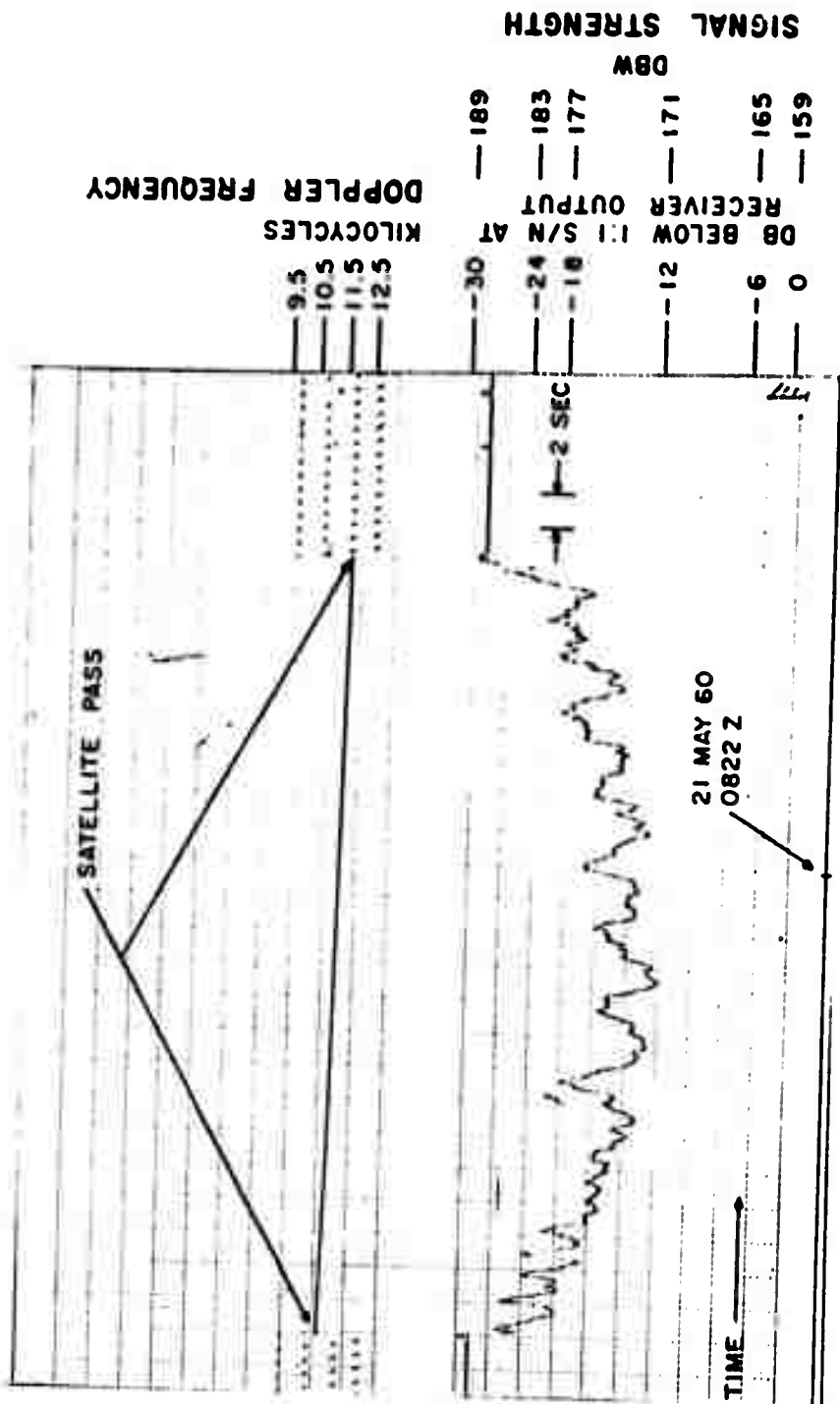
ARPA - BRL DOPLOC DOPPLER RECORD OF
60 EPSILON I REV. 99, FORREST CITY, ARKANSAS
MEASURED 0821:32 Z, PREDICTED 0820 Z
ALTITUDE 200 MILES, 305 MILES EAST FT. SILL
NORTH ANTENNA, SOUTH – NORTH PASS

Fig. 82

SIGNAL STRENGTH
DBW

DOPPLER FREQUENCY
KILOCYCLES

ARPA - BRL DOPLOC DOPPLER RECORD OF
60 EPSILON I REV. 150, FORREST CITY, ARKANSAS
MEASURED 1653:44 Z, PREDICTED 16542
ALTITUDE 287 MILES, 291 MILES EAST FT. SILL
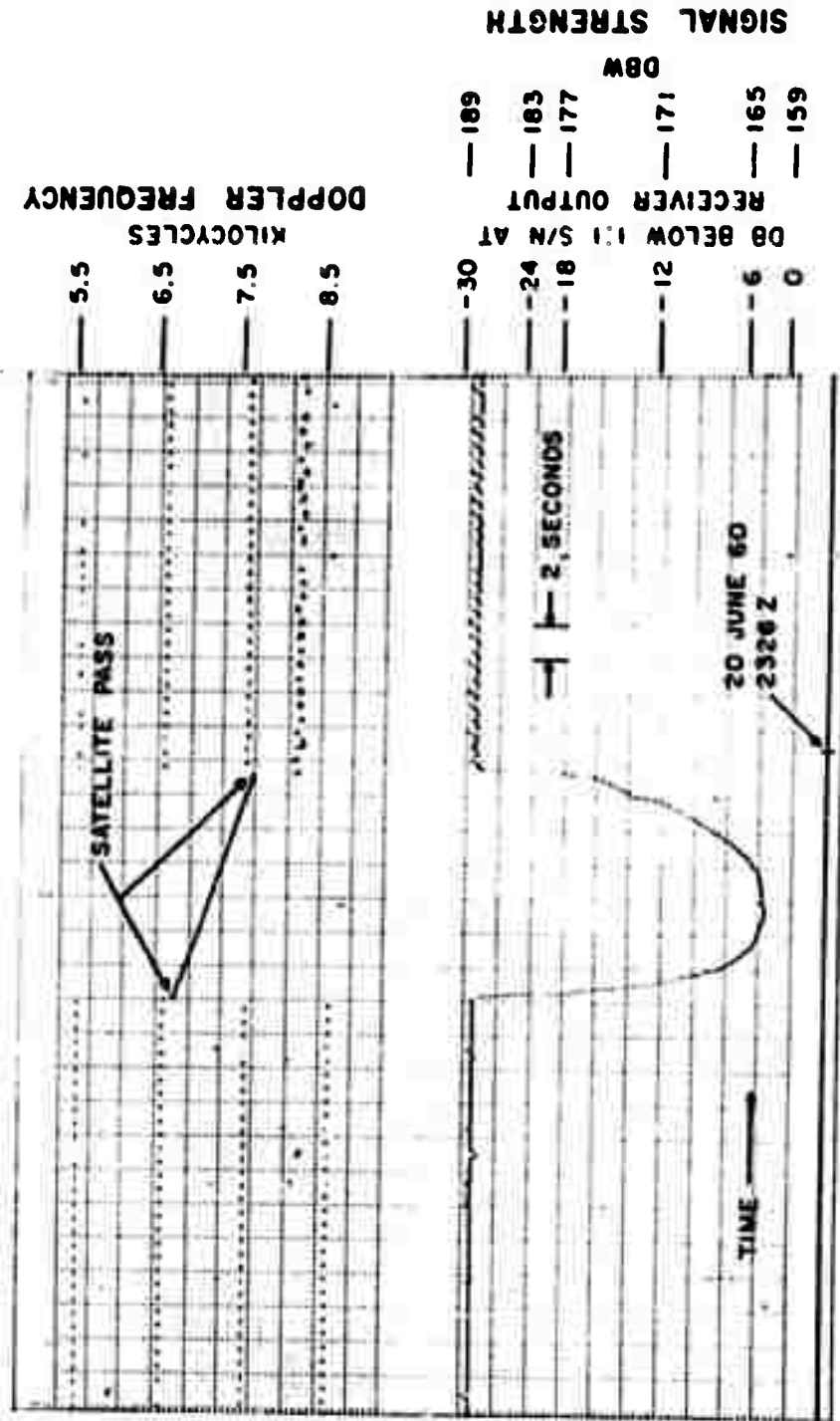SOUTH ANTENNA, NORTH – SOUTH PASS

Fig. 83

139
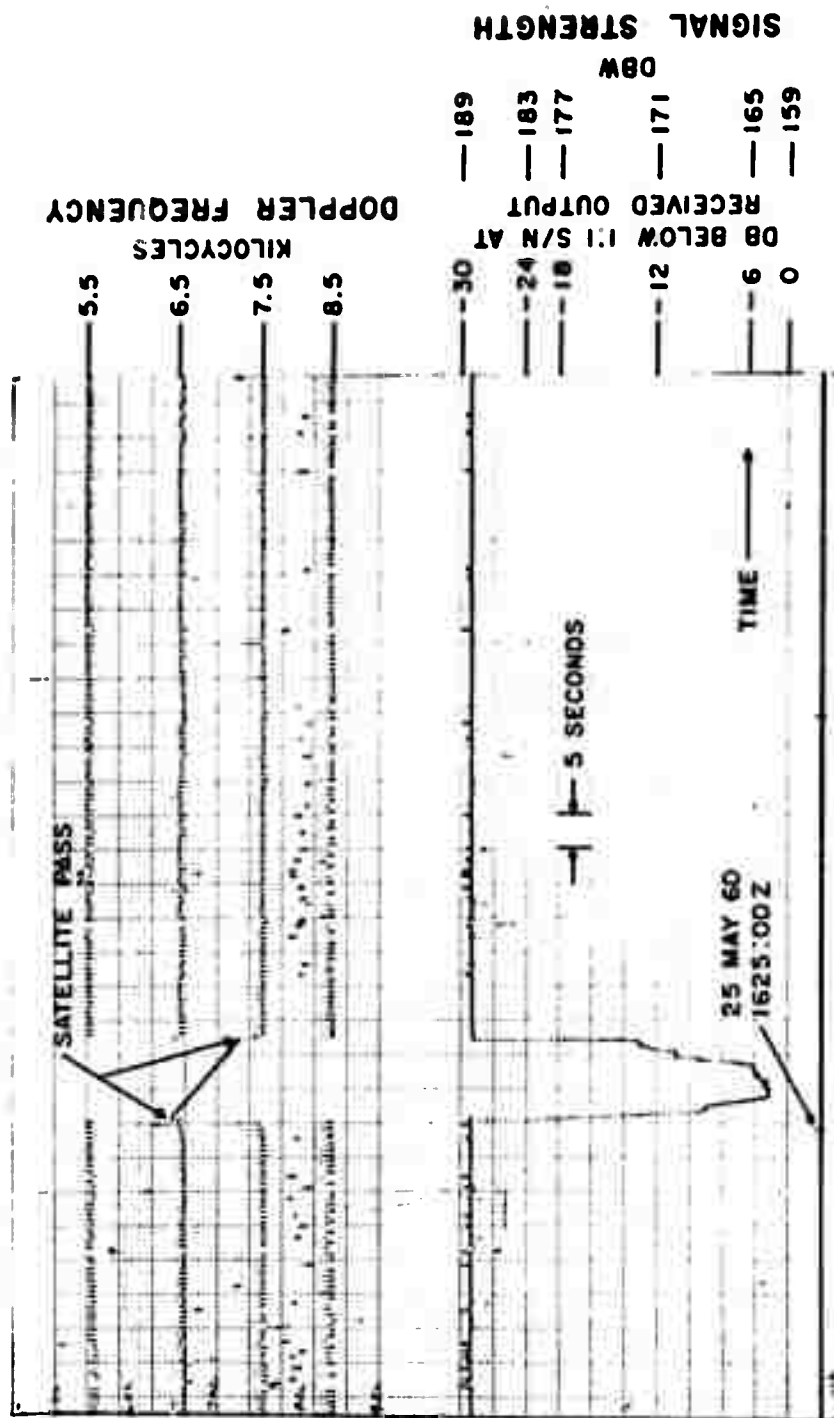
ARPA — BRL DOPLOC DOPPLER RECORD OF
60 EPSILON I REV. 165, FORREST CITY, ARKANSAS
MEASURED 1624:59 Z, PREDICTED 1628 Z
ALTITUDE 288 MILES, 96 MILES EAST FT. SILL
CENTER ANTENNA, NORTH — SOUTH PASS

Fig. 84

SIGNAL STRENGTH
DBW

DOPPLER FREQUENCY
KILOCYCLES
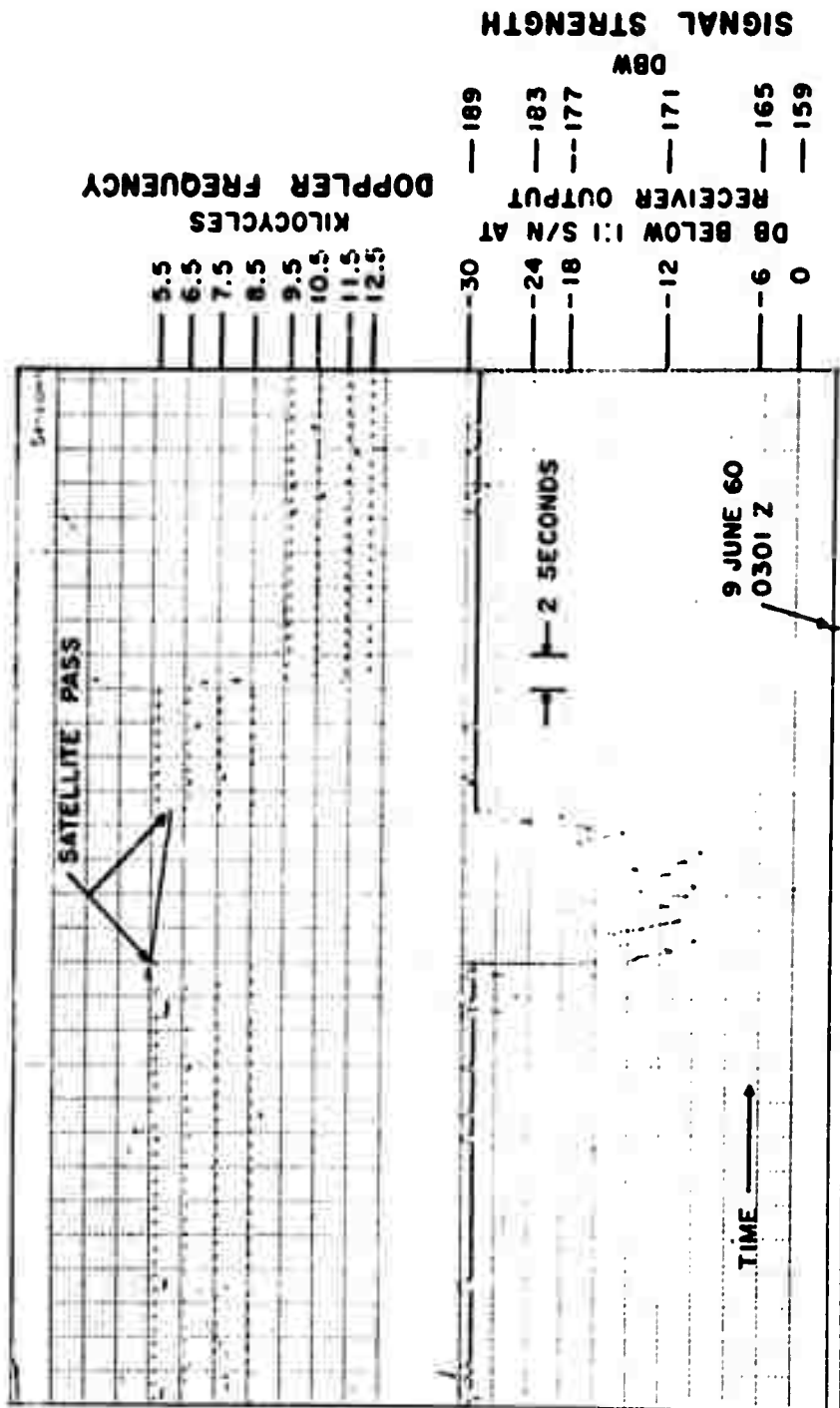
ARPA – BRL DOPPLER RECORD OF
60 EPSILON I REV. 386, FORREST CITY, ARKANSAS
MEASURED 0300:41 Z, PREDICTED 0301 Z
ALTITUDE 230 MILES, 15 MILES EAST FT. SILL
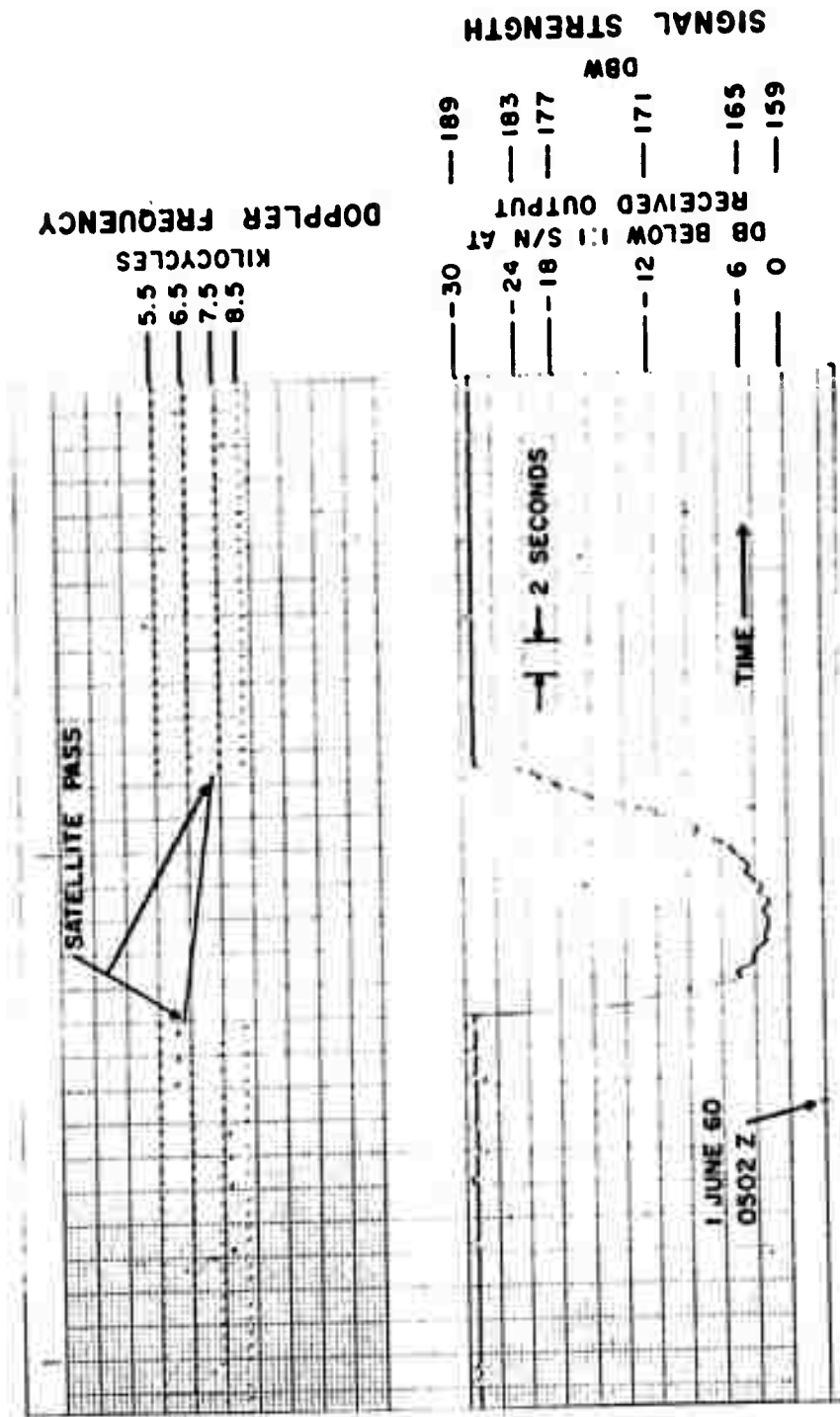CENTER ANTENNA, SOUTH – NORTH PASS

Fig. 85

141

ARPA – BRL DOPLOC DOPPLER RECORD OF
60 EPSILON I REV. 522, FORREST CITY, ARKANSAS
MEASURED 0028.41 Z, PREDICTED 0028 Z
ALTITUDE 225 MILES, 20 MILES EAST FT. SILL
CENTER ANTENNA, SOUTH – NORTH PASS

FIG. 86

ARPA - BRL DOPLOC DOPPLER RECORD OF
60 EPSILON 2 REV. 106, FORREST CITY, ARKANSAS
MEASURED 1733:24Z, PREDICTED 1735 Z
ALTITUDE 208 MILES, 203 MILES WEST FT. SILL
SOUTH ANTENNA, NORTH – SOUTH PASS

Fig. 87

143

SIGNAL STRENGTH
DBW

SATELLITE PASS

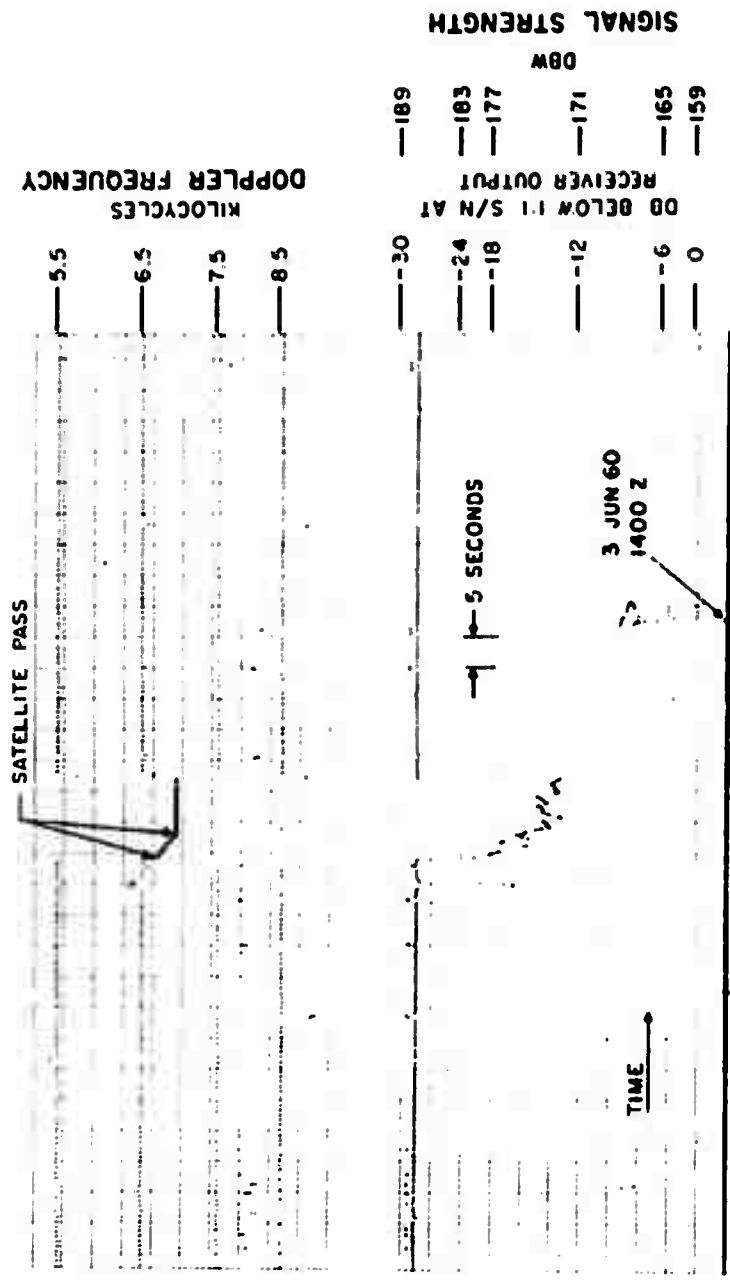DOPPLER FREQUENCY
KILOCYCLES

2 SECONDS

23 MAY 60
1636 Z

TIME

ARPA - BRL DOPLOC DOPPLER RECORD OF
60 EPSILON 2 REV. 137, FORREST CITY, ARKANSAS
MEASURED 1635:46Z, PREDICTED 1639 Z
ALTITUDE 209 MILES, 274 MILES EAST FT. SILL
CENTER ANTENNA, NORTH - SOUTH PASS

Fig. 88

144

ARPA—BRL DOPLOC DOPPLER RECORD OF
60 EPSILON 2 REV 147, FORREST CITY, ARKANSAS
MEASURED CUTOFF 2, PREDICTED 0775 Z
ALTITUDE 260 MILES, 90 MILES EAST FT 141,
CENTER—NORTH ANTENNA, SOUTH—NORTH PASS

Fig. 89

145

SIGNAL STRENGTH

DBW

— 189
— 183
— 177
— 171
— 165
— 159

DOPPLER FREQUENCY
KILOCYCLES

— 9.5
— 10.5
— 11.5
— 12.5

DB BELOW 1:1 S/N AT RECEIVED OUTPUT

— 30
— 24
— 18
— 12
— 6
— 0

2 SECONDS

SATELLITE PASS

TIME →

24 MAY 60
1655 Z

ARPA - BRL DOPLOC DOPPLER RECORD OF
60 EPSILON 2 REV. 153, FORREST CITY, ARKANSAS

MEASURED 1655:14 Z, PREDICTED 1657 Z
ALTITUDE 209 MILES, 112 MILES EAST FT. SILL
SOUTH ANTENNA, NORTH - SOUTH PASS

FIG. 90

146

ARPA – BRL DOPLOC DOPPLER RECORD OF
60 EPSILON 2 REV. 194, FORREST CITY, ARKANSAS
MEASURED 0642 Z, PREDICTED 0638 Z
ALTITUDE 193 MILES, 159 MILES EAST FT. SILL
NORTH ANTENNA, SOUTH – NORTH PASS

Fig. 91

147

SIGNAL STRENGTH
DBW

DOPPLER FREQUENCY
KILOCYCLES

RECEIVER OUTPUT
DB BELOW 1:1 S/N AT

SATELLITE PASS

5 SECONDS

3 JUN 60
0355 Z

TIME
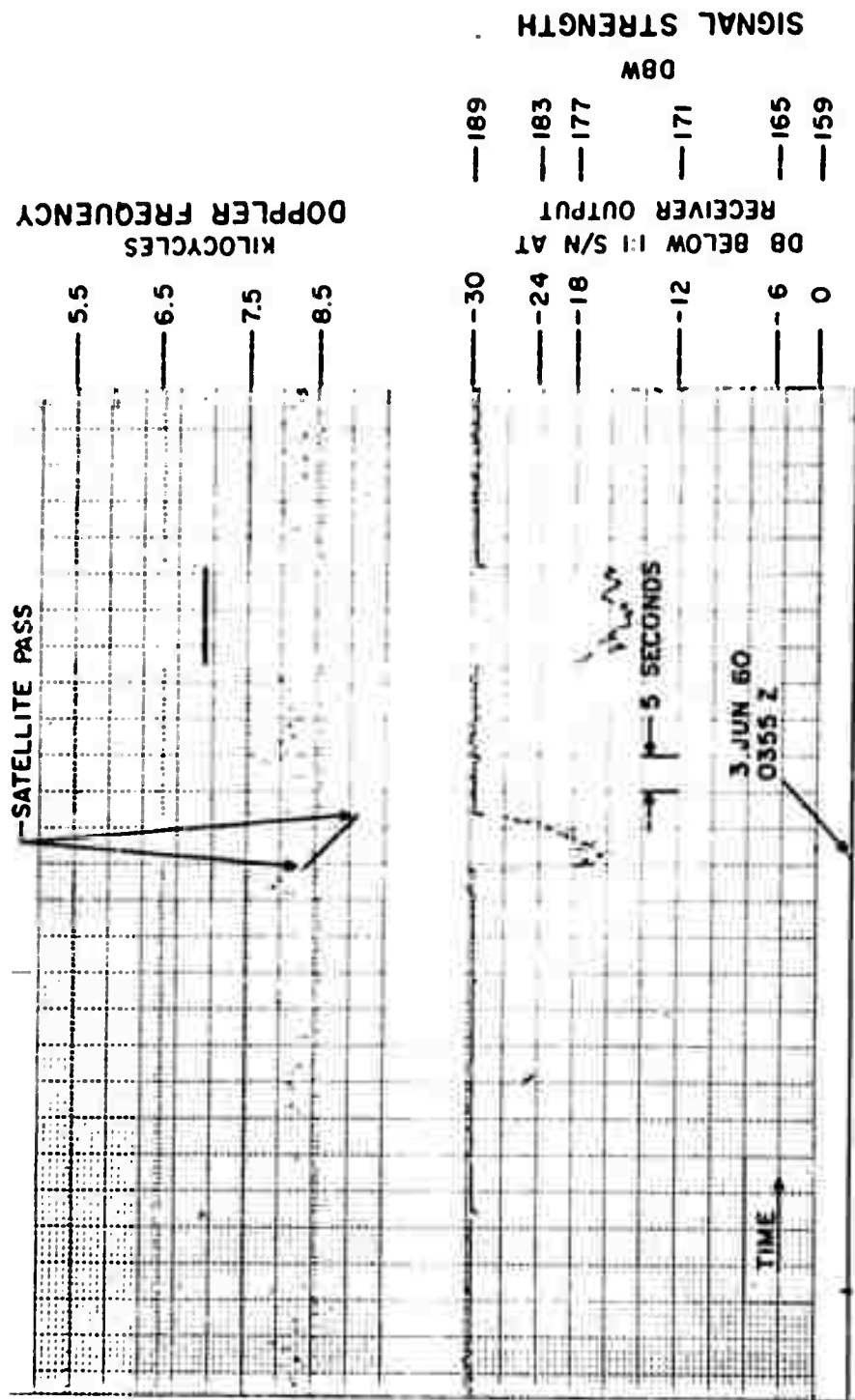
ARPA — BRL DOPLOC DOPPLER RECORD OF
60 EPSILON 2 REV. 303, FORREST CITY, ARKANSAS

MEASURED 0354:58 Z, PREDICTED 0356 Z
ALTITUDE 213 MILES, 420 MILES EAST FT. SILL
CENTER ANTENNA, SOUTH—NORTH PASS

FIG. 92

148

SIGNAL STRENGTH
DBW

189 183 177   171   165 159

DOPPLER FREQUENCY
KILOCYCLES

RECEIVER OUTPUT
DB BELOW 1:1 S/N AT

5.5 6.5 7.5 8.5

-30 -24 -18   -12   -6 0

SATELLITE PASS

5 SECONDS

3 JUN 60
1326 Z

TIME
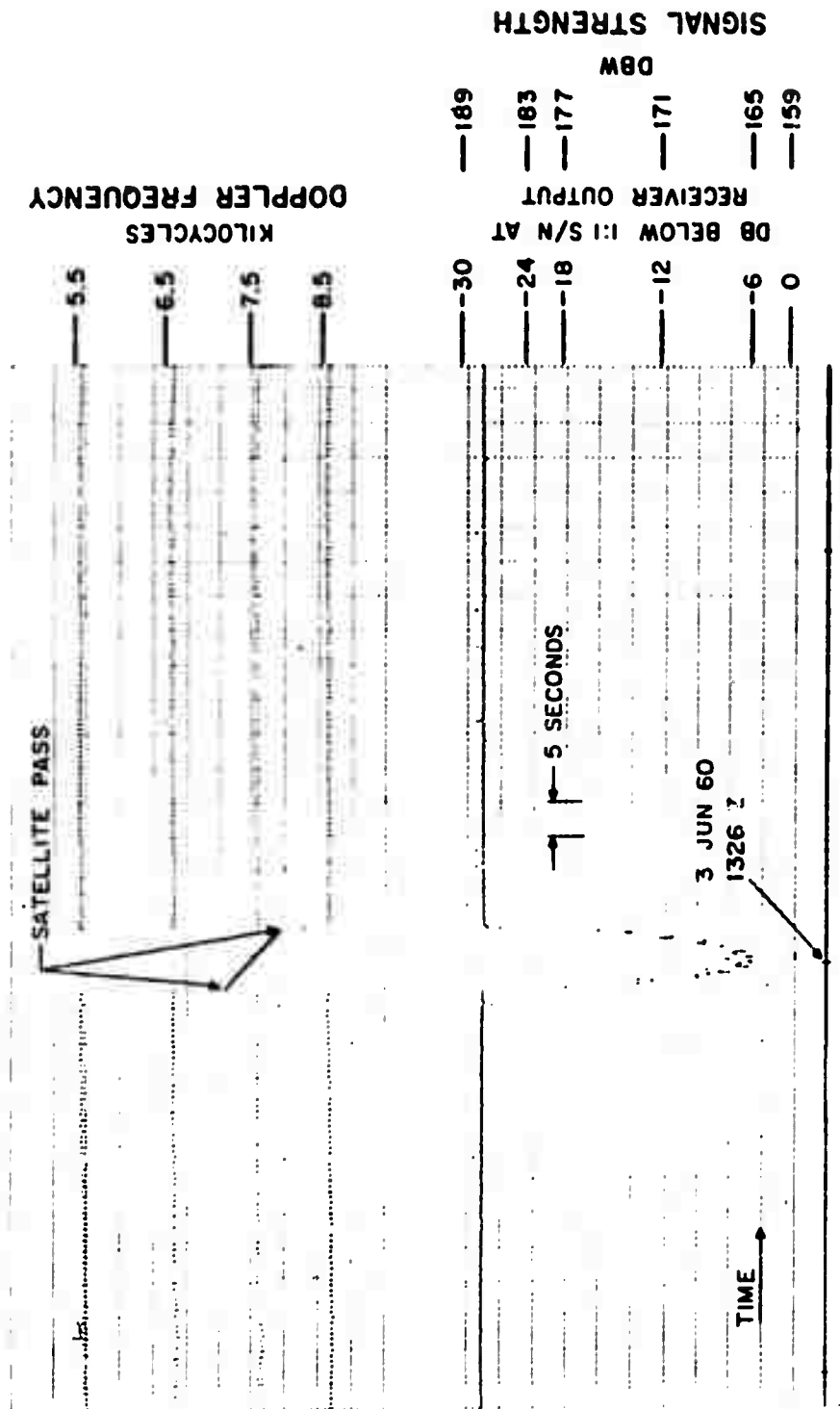
ARPA — BRL DOPLOC DOPPLER RECORD OF
60 EPSILON 2 REV. 309, FORREST CITY, ARKANSAS
MEASURED 1325:57 Z, PREDICTED 1327 Z
ALTITUDE 205 MILES, 305 MILES EAST FT. SILL
CENTER ANTENNA, NORTH—SOUTH PASS

Fig. 93

149

SIGNAL STRENGTH
DBW

DOPPLER FREQUENCY
KILOCYCLES

RECEIVED OUTPUT
DB BELOW 1:1 S/N AT

ARPA — BRL DOPLOC DOPPLER DOPPLER RECORD OF
60 EPSILON 2 REV. 356, FORREST CITY, ARKANSAS
MEASURED 1240:39 Z, PREDICTED 1238 Z
ALTITUDE 201 MILES, 30 MILES EAST FT. SILL
NORTH ANTENNA, NORTH – SOUTH PASS

Fig. 94

150

SIGNAL STRENGTH

DBW

DOPPLER FREQUENCY

KILOCYCLES

SATELLITE PASS

2 SECONDS

2218:14 Z
22 JUNE 60

TIME

RECEIVER OUTPUT

DB BELOW 1:1 S/N AT

ARPA – BRL DOPLOC DOPPLER RECORD OF
60 EPSILON 2 REV. 617, FORREST CITY, ARKANSAS
MEASURED 2218:14 Z, PREDICTED 2218 Z
ALTITUDE 203 MILES, 77 MILES EAST FT. SILL
CENTER ANTENNA, SOUTH – NORTH PASS   Fig. 95

151

SIGNAL STRENGTH

ARPA – BRL DOPLOC DOPPLER RECORD OF
60 EPSILON 3 REV. 280, FORREST CITY, ARKANSAS
MEASURED 0435:21 Z, PREDICTED 0435 Z
ALTITUDE 232 MILES, 358 MILES EAST FT. SILL
CENTER ANTENNA, SOUTH – NORTH PASS

Fig. 96

SIGNAL STRENGTH

DOPPLER FREQUENCY

SATELLITE PASS

5 SECONDS

TIME

2 JUNE 60
0440 Z
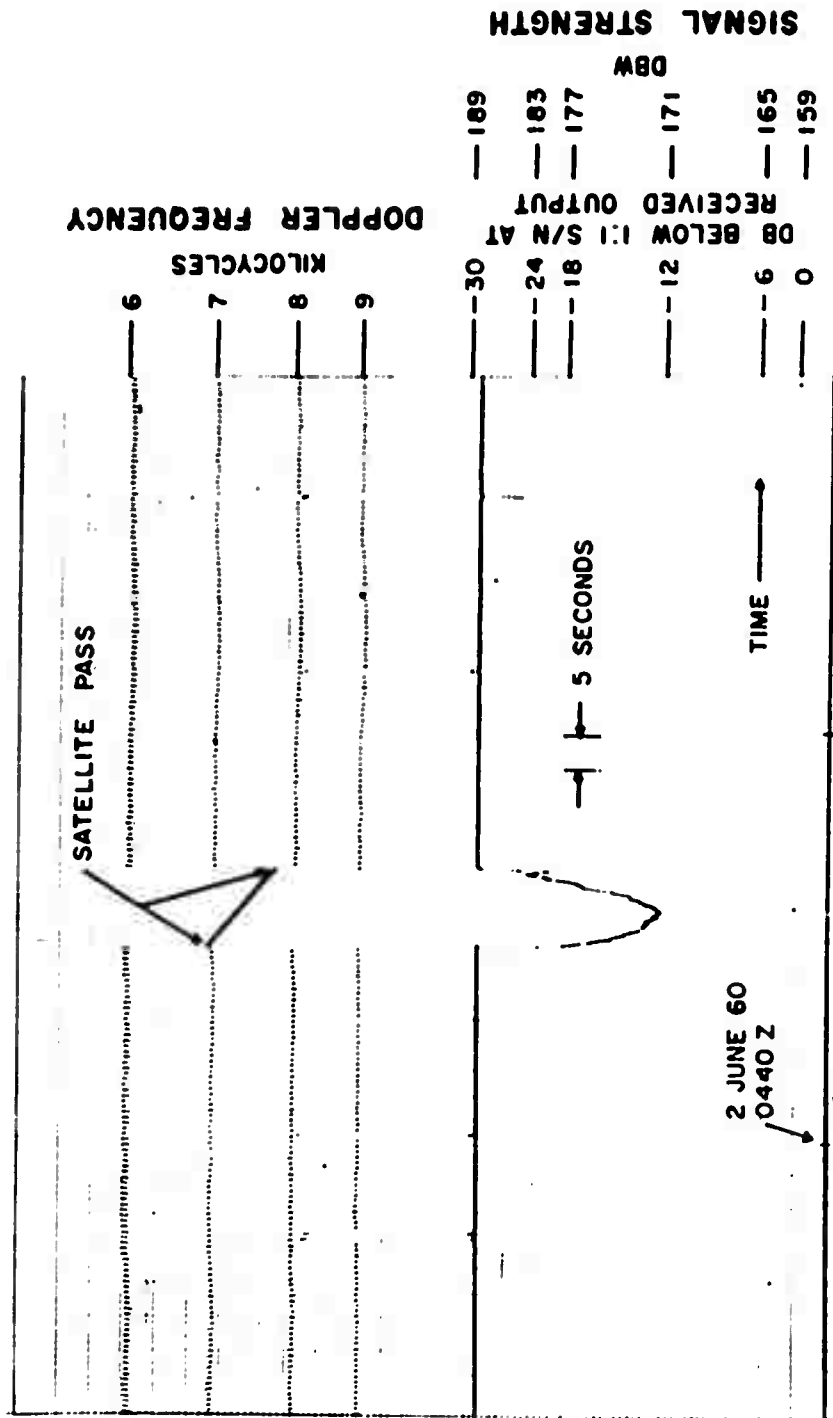
ARPA – BRL DOPLOC DOPPLER RECORD OF
60 EPSILON 4 REV. 280, FORREST CITY, ARKANSAS
MEASURED 0441:29 Z, PREDICTED 0441 Z
ALTITUDE 240 MILES, 270 MILES EAST FT. SILL
CENTER ANTENNA, SOUTH – NORTH PASS

Fig. 97

153

ARPA – BRL DOPLOC DOPPLER RECORD OF
60 EPSILON 5 REV. 569, FORREST CITY, ARKANSAS
MEASURED 2325:46 Z, PREDICTED 2327 Z
ALTITUDE 205 MILES, 231 MILES EAST FT. SILL
CENTER ANTENNA, SOUTH – NORTH PASS

Fig. 98

154

SIGNAL STRENGTH

DBW

DOPPLER FREQUENCY

KILOCYCLES

SATELLITE PASS

RECEIVED OUTPUT

DB BELOW 1:1 S/N AT

2 SECONDS

TIME

1 JUNE 60

0502 Z

ARPA - BRL DOPLOC DOPPLER RECORD OF

60 EPSILON 6 REV. 265, FORREST CITY, ARKANSAS

MEASURED 0502:06 Z, PREDICTED 0502 Z

ALTITUDE 218 MILES, 210 MILES EAST FT. SILL

CENTER ANTENNA, SOUTH – NORTH PASS

Fig. 99

155

SIGNAL STRENGTH

DBW

189 183 177   171   165 159

DOPPLER FREQUENCY
KILOCYCLES

RECEIVER OUTPUT
DB BELOW 1:1 S/N AT

5.5 6.5 7.5 8.5   -30 -24 -18   -12   -6 0

SATELLITE PASS

5 SECONDS

3 JUN 60
1400 Z

TIME

ARPA – BRL DOPLOC DOPPLER RECORD OF
60 EPSILON 6 REV. 301, FORREST CITY, ARKANSAS
MEASURED 1359:22 Z , PREDICTED 1400 Z
ALTITUDE 233 MILES, 190 MILES EAST FT SILL
CENTER ANTENNA , NORTH – SOUTH PASS

FIG. 100
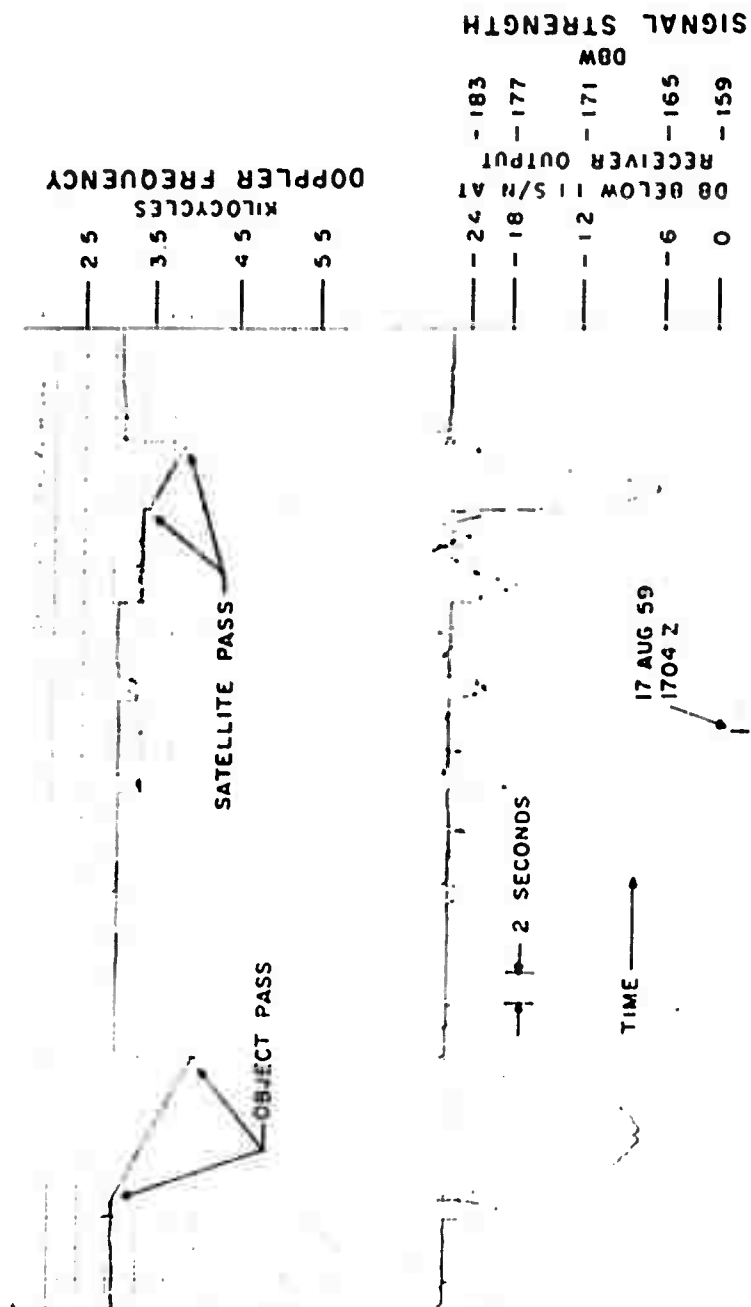
156

ARPA-BRL DOPLOC DOPPLER RECORD OF UNIDENTIFIED
OBJECT AND 59 EPSILON FORREST CITY, ARKANSAS

UNIDENTIFIED OBJECT
MEASURED 1703:30 Z, CENTER ANTENNA
ALTITUDE 125 MILES, OVERHEAD FT. SILL

59 EPSILON REV 60
MEASURED 1704.14 Z, PREDICTED 1701 Z
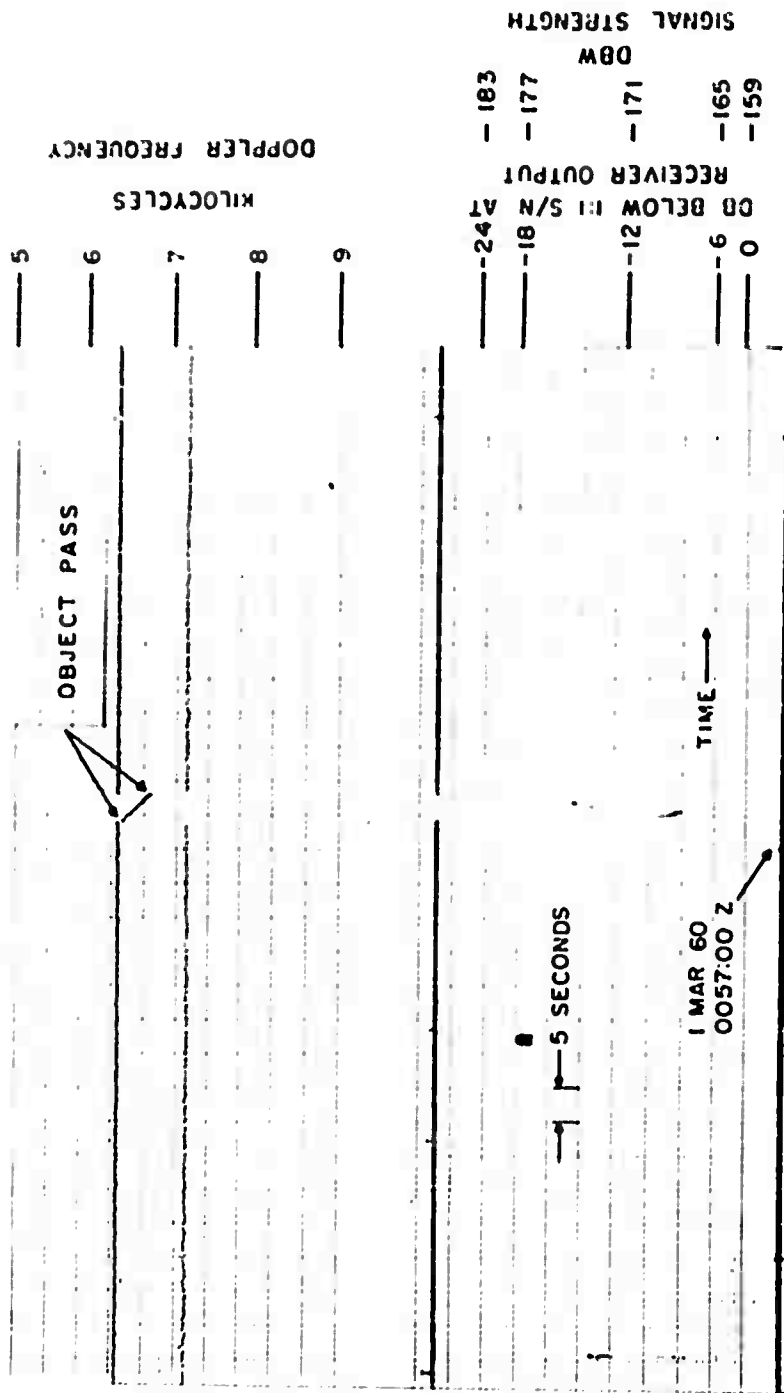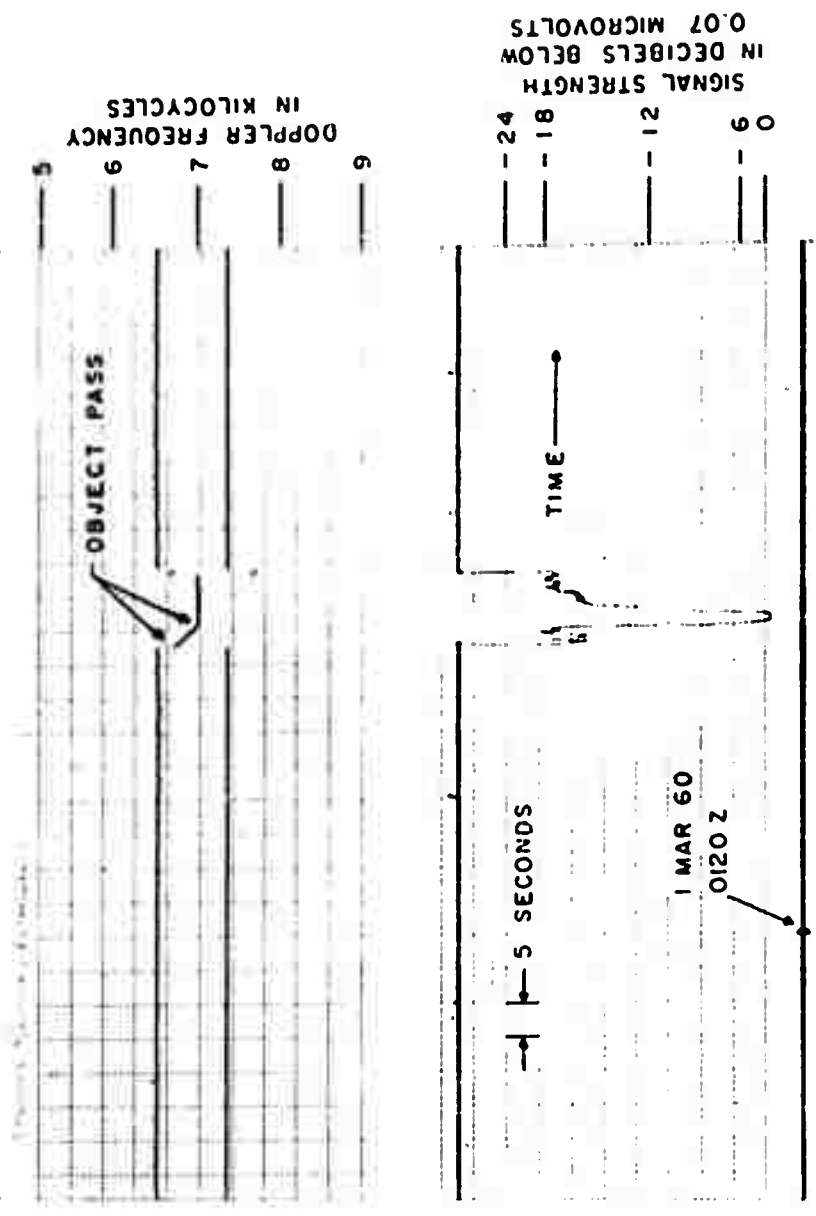ALTITUDE 140 MILES, 76 MILES WEST FT. SILL
CENTER ANTENNA, N-S PASS

Fig. 101

157

ARPA-BRL DOPLOC DOPPLER RECORD OF
UNIDENTIFIED OBJECT FORREST CITY, ARKANSAS
MEASURED 1514 01 Z, CENTER ANTENNA
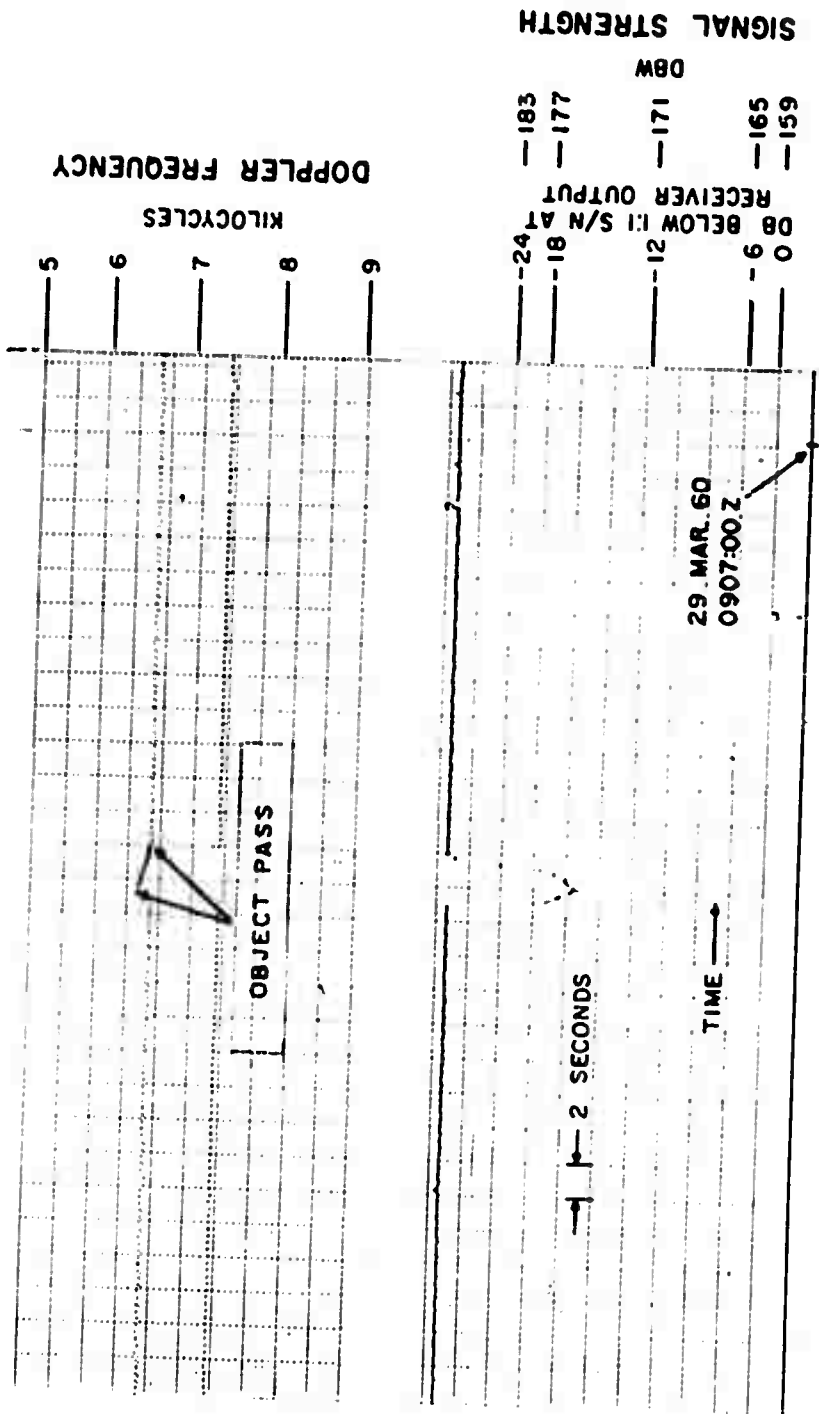ALTITUDE 432 MILES, 318 MILES EAST FT. SILL

Fig. 102

158

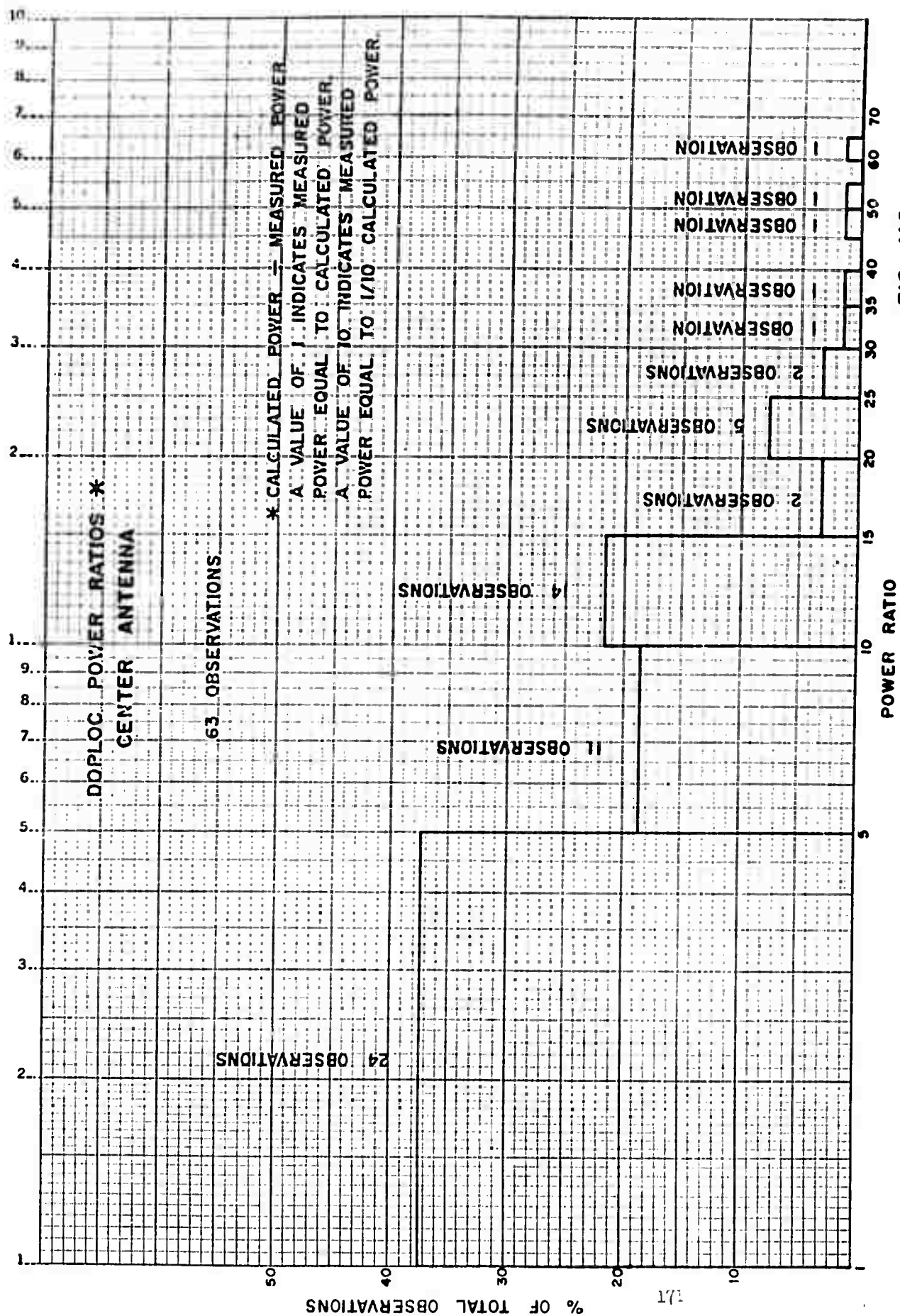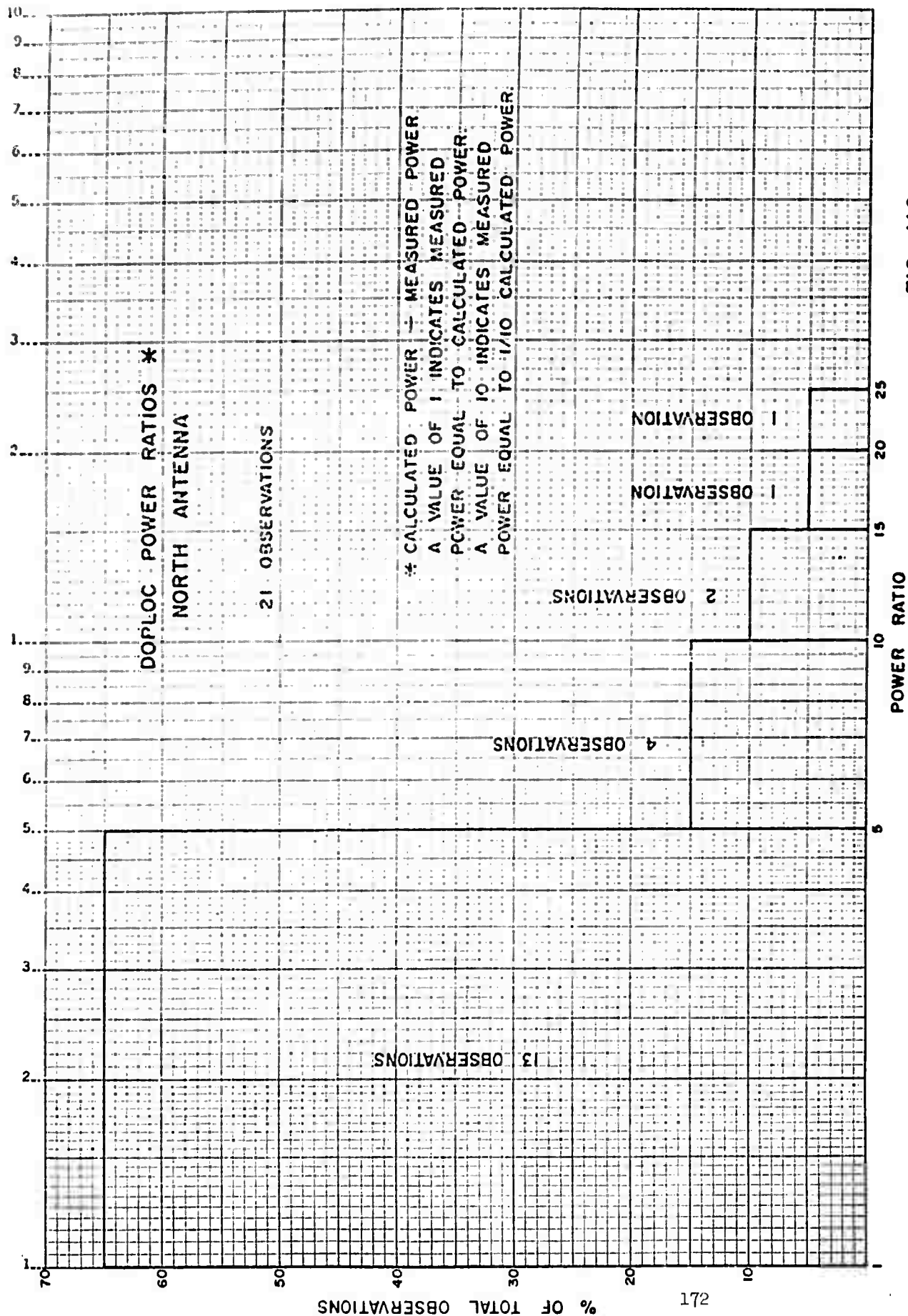DOPPLER FREQUENCY
IN KILOCYCLES

2.5   3.5   4.5   5.5

SIGNAL STRENGTH
IN DECIBELS BELOW
0.07 MICROVOLTS

-24   -18   -12   -6   0

OBJECT PASS

TIME

5 SECONDS

22 SEP 59
1643 Z

ARPA-BRL DOPLOC DOPPLER RECORD OF
UNIDENTIFIED OBJECT FORREST CITY, ARKANSAS
MEASURED 1643:04 Z, CENTER ANTENNA
ALTITUDE 398 MILES, 140 MILES EAST FT. SILL

Fig. 103

159

DOPPLER FREQUENCY
IN KILOCYCLES

SIGNAL STRENGTH
IN DECIBELS BELOW
0.07 MICROVOLTS

OBJECT PASS

5 SECONDS

TIME

1 OCT 5,9
0235 Z

ARPA-BRL DOPLOC DOPPLER RECORD OF
UNIDENTIFIED OBJECT FORREST CITY, ARKANSAS
MEASURED 0235:22 Z, CENTER ANTENNA
ALTITUDE 190 MILES, 117 MILES EAST FT. SILL

Fig. 104
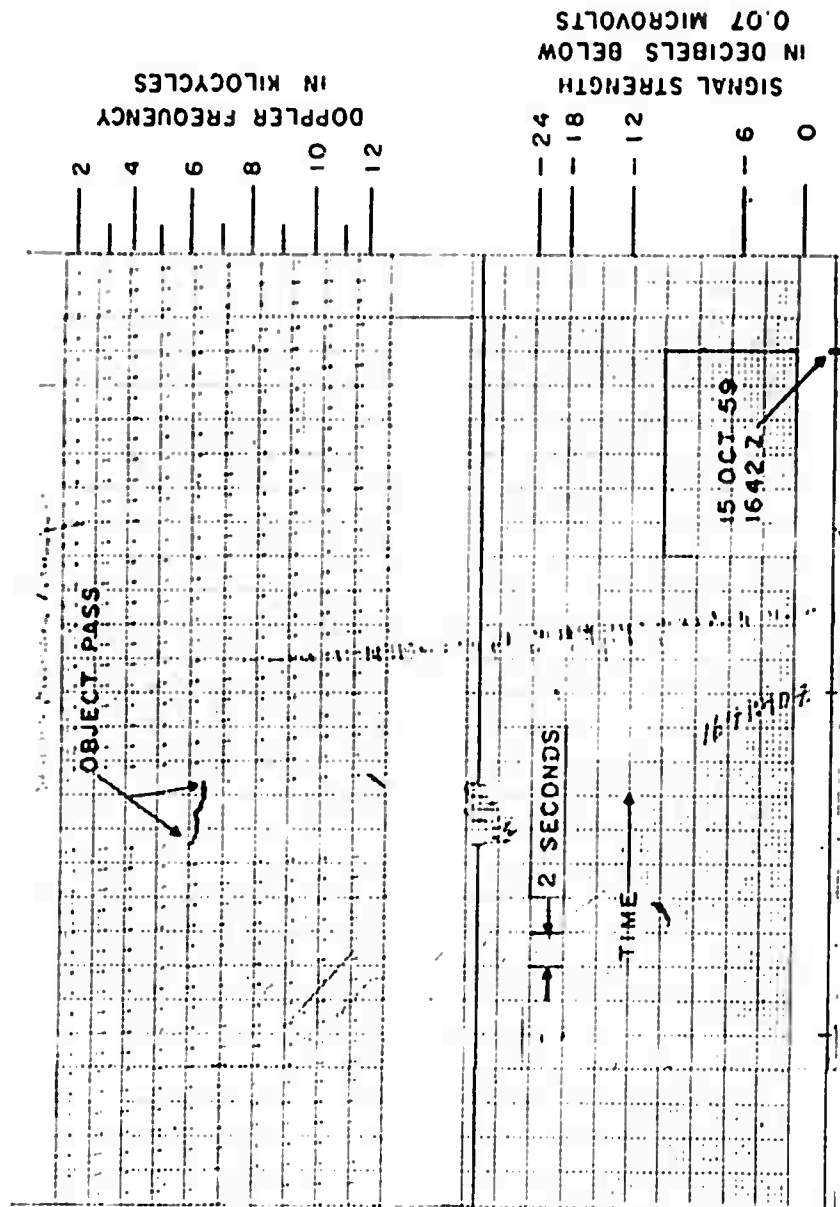
160

ARPA-BRL DOPLOC DOPPLER RECORD OF
UNIDENTIFIED OBJECT FORREST CITY, ARKANSAS
MEASURED 1641:31Z, CENTER ANTENNA
ALTITUDE 178 MILES, 115 MILES EAST FT. SILL

FIG. 105
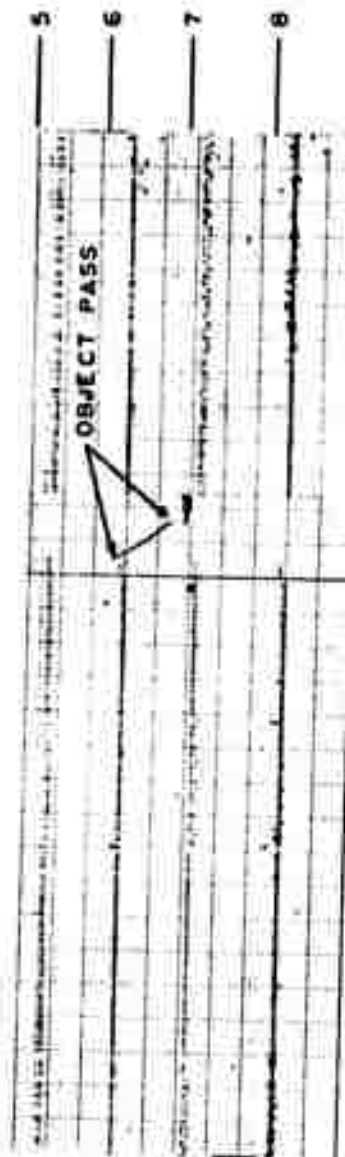
161

DOPPLER FREQUENCY
IN KILOCYCLES

SIGNAL STRENGTH
IN DECIBELS BELOW
0.07 MICROVOLTS

OBJECT PASS

22:59:00 Z

5 SECONDS

22:58:00 Z

11 DEC 59
22:57:00 Z

ARPA - BRL DOPLOC DOPPLER RECORD OF
UNIDENTIFIED OBJECT FORREST CITY, ARKANSAS
CENTER ANTENNA MEASURED 2258:01 Z
ALTITUDE 100 MILES, 20 MILES WEST FT. SILL

Fig. 106

162

DOPPLER FREQUENCY
IN KILOCYCLES

5
6
7
8

OBJECT PASS

1

SIGNAL STRENGTH
IN DECIBELS BELOW
0 07 MICROVOLTS

-24
-18
-12
-6
0

TIME

5 SECONDS

16 DEC 59
1843 Z
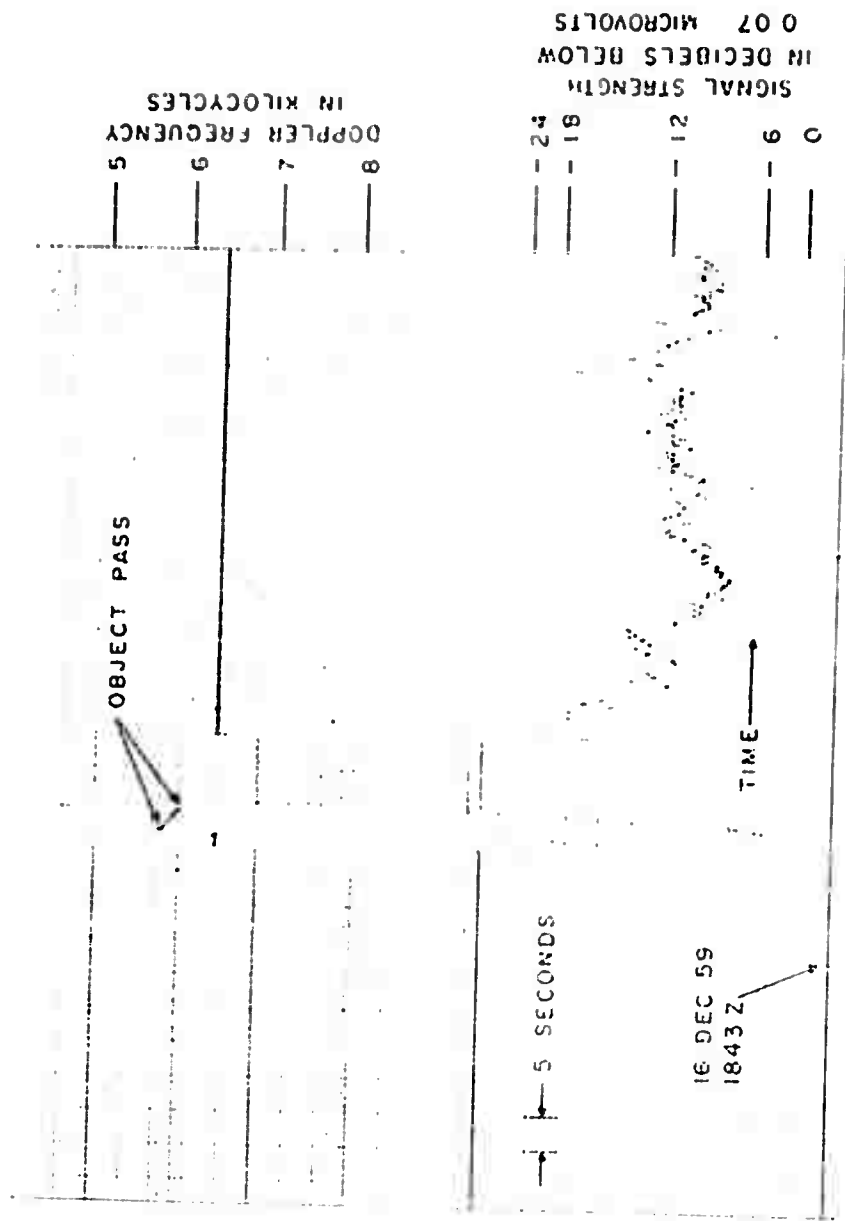
ARPA-9RL DOPLOC DOPPLER RECORD OF
UNIDENTIFIED OBJECT FORREST CITY, ARKANSAS
MEASURED 1843·18 Z, CENTER ANTENNA
ALTITUDE 198 MILES, 165 MILES EAST FT SILL
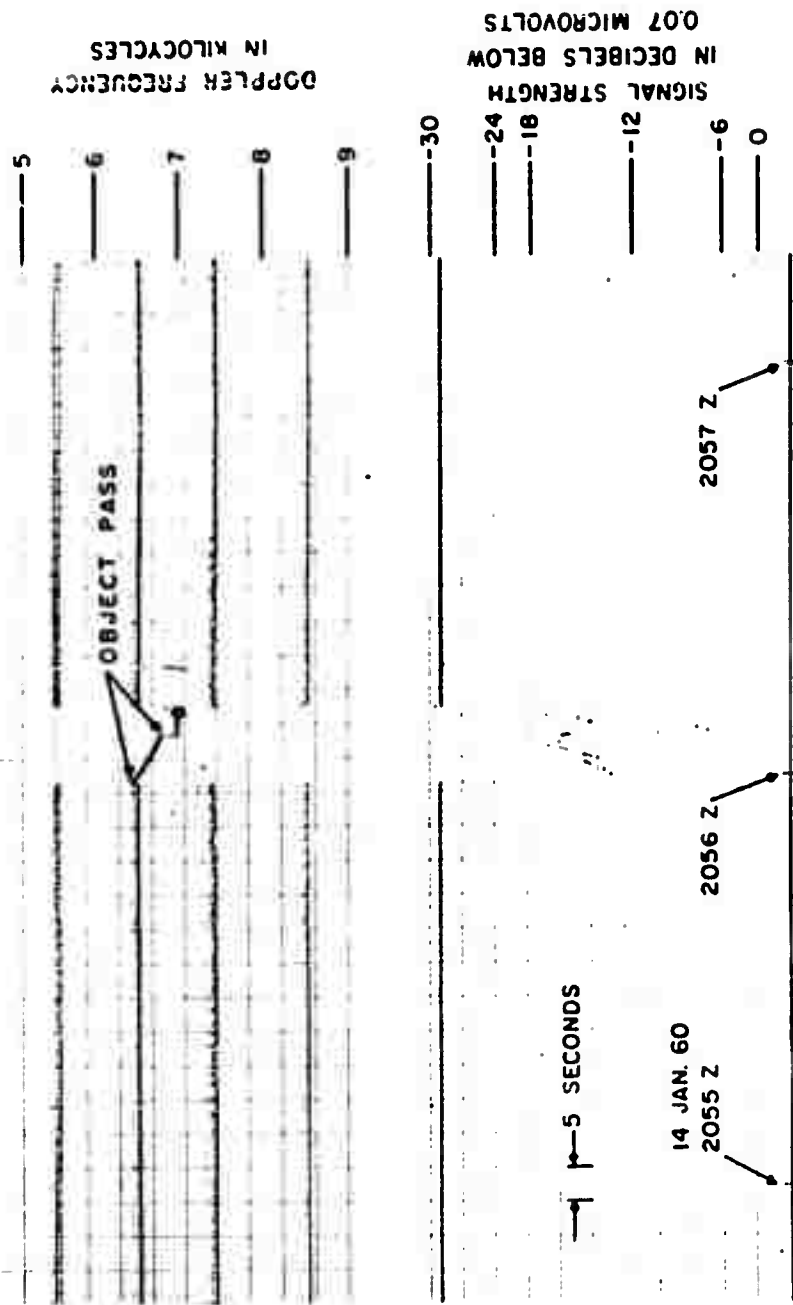
Fig. 107

165

DOPPLER FREQUENCY IN KILOCYCLES

OBJECT PASS

SIGNAL STRENGTH IN DECIBELS BELOW 0.07 MICROVOLTS

2057 Z

2056 Z

5 SECONDS

14 JAN. 60
2055 Z

ARPA-BRL DOPLOC DOPPLER RECORD OF
UNIDENTIFIED OBJECT, FORREST CITY, ARKANSAS
CENTER ANTENNA MEASURED 2056:00 Z
ALTITUDE 485 MILES, 140 MILES EAST FT. SILL

Fig. 108
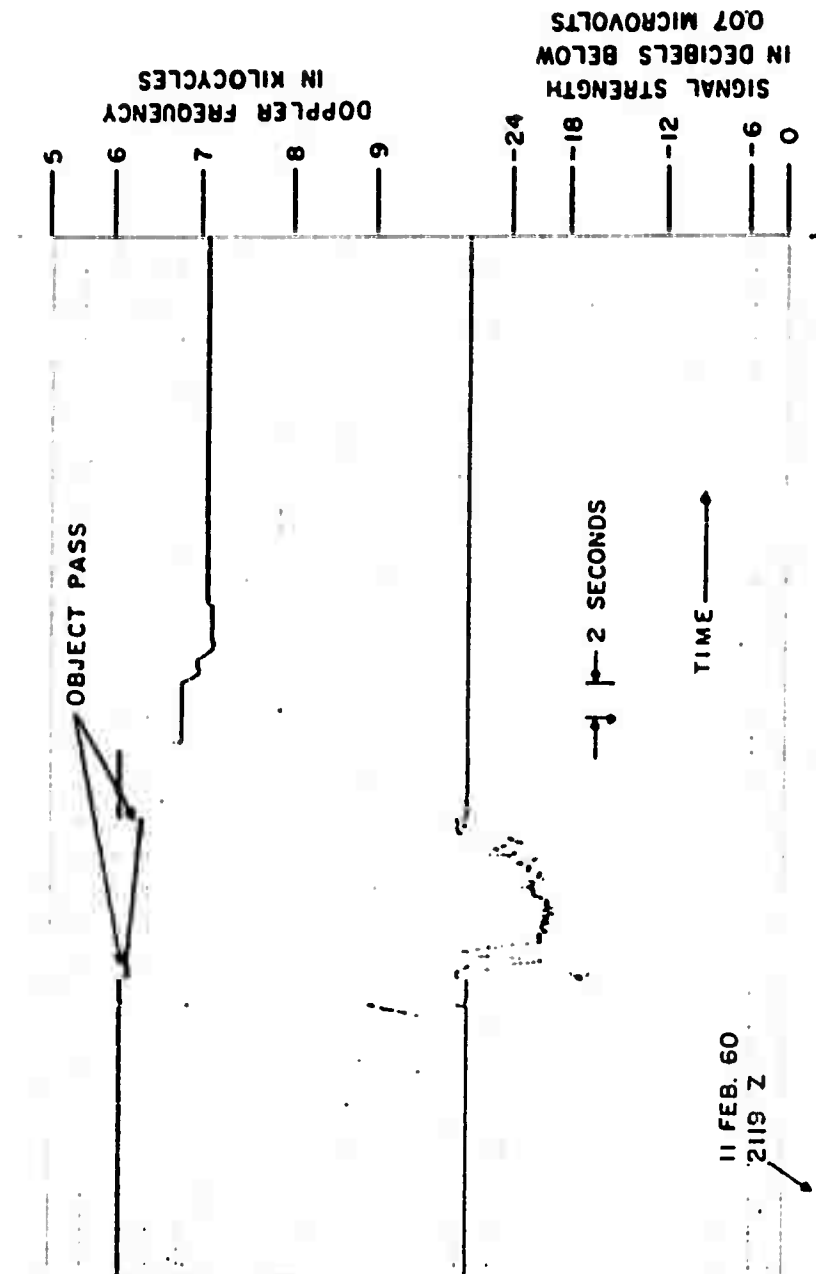
164

DOPPLER FREQUENCY
IN KILOCYCLES

SIGNAL STRENGTH
IN DECIBELS BELOW
0.07 MICROVOLTS

OBJECT PASS

2 SECONDS

TIME

11 FEB. 60
2119 Z

ARPA—BRL DOPLOC DOPPLER RECORD OF
UNIDENTIFIED OBJECT FORREST CITY, ARKANSAS
MEASURED 2119:13 Z, CENTER ANTENNA
ALTITUDE 900 MILES, OVERHEAD FORT SILL

Fig. 109

165

DOPPLER FREQUENCY
IN KILOCYCLES

5
6
7
8
9

SIGNAL STRENGTH
IN DECIBELS BELOW
0.07 MICROVOLTS

24
18
12
6
0

OBJECT PASS

2 SECONDS

12 FEB 60
2146 Z

TIME
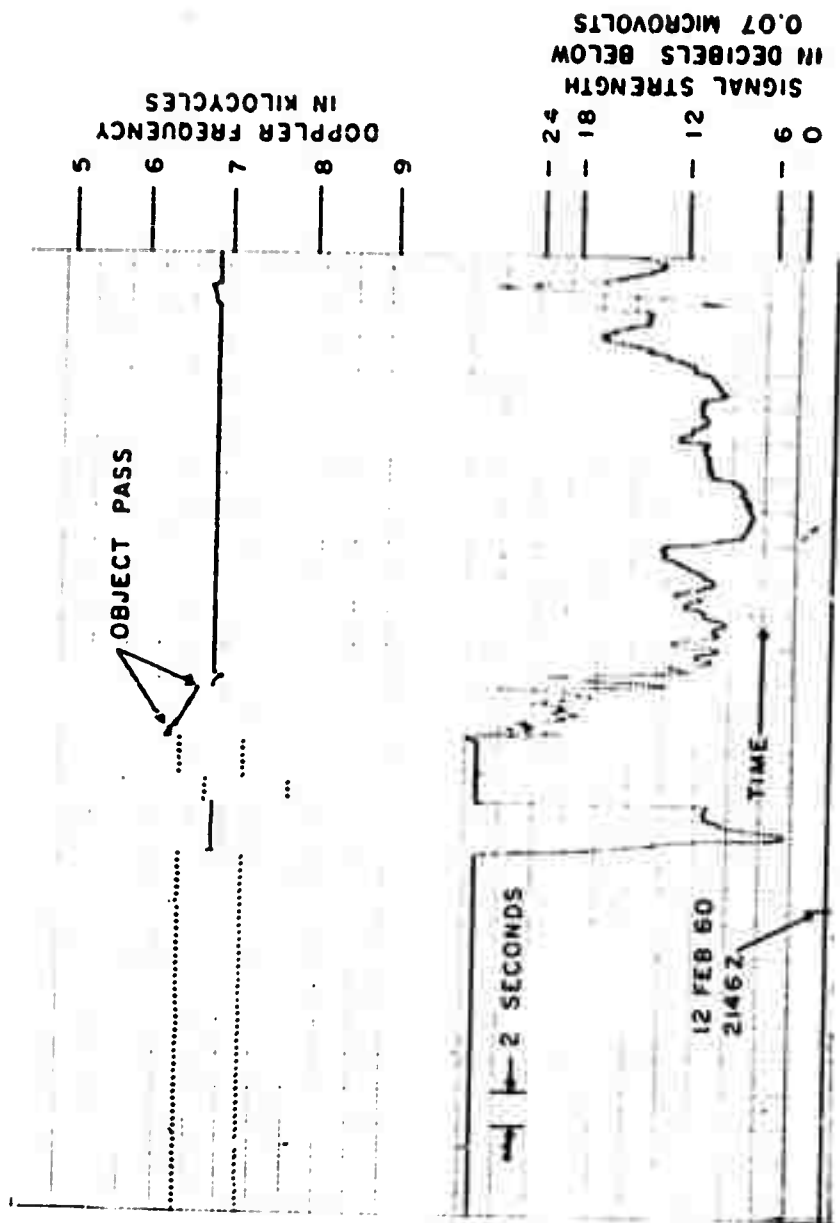
ARPA-BRL DOPLOC DOPPLER RECORD OF
UNIDENTIFIED OBJECT FORREST CITY, ARKANSAS
MEASURED 2146:10 Z, CENTER ANTENNA
ALTITUDE 190 MILES, 135 MILES EAST FT. SILL

Fig. 110

DOPPLER FREQUENCY
IN KILOCYCLES

5 — 6 — 7 — 8 — 9

OBJECT PASS

SIGNAL STRENGTH
IN DECIBELS BELOW
0 0 7 MICROVOLTS

24 — 18 — 12 — 6 — 0

TIME →

2 SECONDS

18 FEB 60
0101 Z

ARPA-BRL DOPLOC DOPPLER RECORD OF
UNIDENTIFIED OBJECT FORREST CITY, ARKANSAS
MEASURED 0101 22 Z, CENTER ANTENNA
ALTITUDE 265 MILES, 40 MILES EAST FT SILL

Fig. 111

ARPA—BRL DOPLOC DOPPLER RECORD OF
UNIDENTIFIED OBJECT FORREST CITY, ARKANSAS

MEASURED 0057:04 Z, CENTER ANTENNA
ALTITUDE 190 MILES, 130 MILES EAST FT. SILL

Fig. 112

168

DOPPLER FREQUENCY IN KILOCYCLES

OBJECT PASS

SIGNAL STRENGTH IN DECIBELS BELOW 0.07 MICROVOLTS

TIME

5 SECONDS

1 MAR 60
0120 Z

ARPA-BRL DOPLOC DOPPLER RECORD OF
UNIDENTIFIED OBJECT FORREST CITY, ARKANSAS
MEASURED 0120:43 Z, CENTER ANTENNA
ALTITUDE 195 MILES, 117 MILES EAST FT. SILL

Fig. 113

SIGNAL STRENGTH

DBW

DOPPLER FREQUENCY

KILOCYCLES

RECEIVER OUTPUT

DB BELOW 1:1 S/N AT

OBJECT PASS

29 MAR. 60
0907:00.Z

2 SECONDS

TIME

ARPA – BRL DOPLOC DOPPLER RECORD OF
UNIDENTIFIED OBJECT, FORREST CITY, ARKANSAS
MEASURED 0906:33 Z, CENTER ANTENNA
ALTITUDE 300 MILES, 90 MILES WEST OF FT. SILL

Fig. 114

170

DOPLOC POWER RATIOS *
CENTER ANTENNA

63 OBSERVATIONS

* CALCULATED POWER = MEASURED POWER

A VALUE OF .1 INDICATES MEASURED
POWER EQUAL TO CALCULATED POWER.

A VALUE OF 10. INDICATES MEASURED
POWER EQUAL TO 1/10 CALCULATED POWER.

FIG. 115

POWER RATIO

% OF TOTAL OBSERVATIONS

24 OBSERVATIONS

11 OBSERVATIONS

14 OBSERVATIONS

2 OBSERVATIONS

2 OBSERVATIONS

5 OBSERVATIONS

2 OBSERVATIONS

1 OBSERVATION

1 OBSERVATION

1 OBSERVATION

1 OBSERVATION

1 OBSERVATION

1 OBSERVATION

FIG. 116

DOPLOC POWER RATIOS *

NORTH ANTENNA

21 OBSERVATIONS

* CALCULATED POWER ÷ MEASURED POWER
A VALUE OF 1 INDICATES MEASURED
POWER EQUAL TO CALCULATED POWER.
A VALUE OF 10 INDICATES MEASURED
POWER EQUAL TO 1/10 CALCULATED POWER.

POWER RATIO

% OF TOTAL OBSERVATIONS

172

DOPLOC POWER RATIOS *

SOUTH ANTENNA

21 OBSERVATIONS

* CALCULATED POWER ÷ MEASURED POWER
A VALUE OF 1 INDICATES MEASURED
POWER EQUAL TO CALCULATED POWER
A VALUE OF 10 INDICATES MEASURED
POWER EQUAL TO 1/10 CALCULATED POWER

FIG. 117

POWER RATIO

% OF TOTAL OBSERVATIONS

1 OBSERVATION

3 OBSERVATIONS

4 OBSERVATIONS

3 OBSERVATIONS

0 OBSERVATIONS

174

DDPLDC POWER RATIOS *
CENTER, NORTH, SOUTH ANTENNAS COMBINED

105 OBSERVATIONS

* CALCULATED POWER ÷ MEASURED POWER.
A VALUE OF 1 INDICATES MEASURED
POWER EQUAL TO CALCULATED POWER.
A VALUE OF 10 INDICATES MEASURED
POWER EQUAL TO 1/10 CALCULATED POWER.

1 OBSERVATION
1 OBSERVATION
1 OBSERVATION
1 OBSERVATION
1 OBSERVATION
2 OBSERVATIONS
7 OBSERVATIONS
6 OBSERVATIONS
20 OBSERVATIONS
10 OBSERVATIONS
47 OBSERVATIONS

POWER RATIO

% OF TOTAL OBSERVATIONS

FIG. 118

175

DOPPLER RECORD OF ACTIVE N-S TRACK OF
58 DELTA (SPUTNIK III) REV. 9958 AT
ABERDEEN PROVING GROUND, MARYLAND

Fig. 119
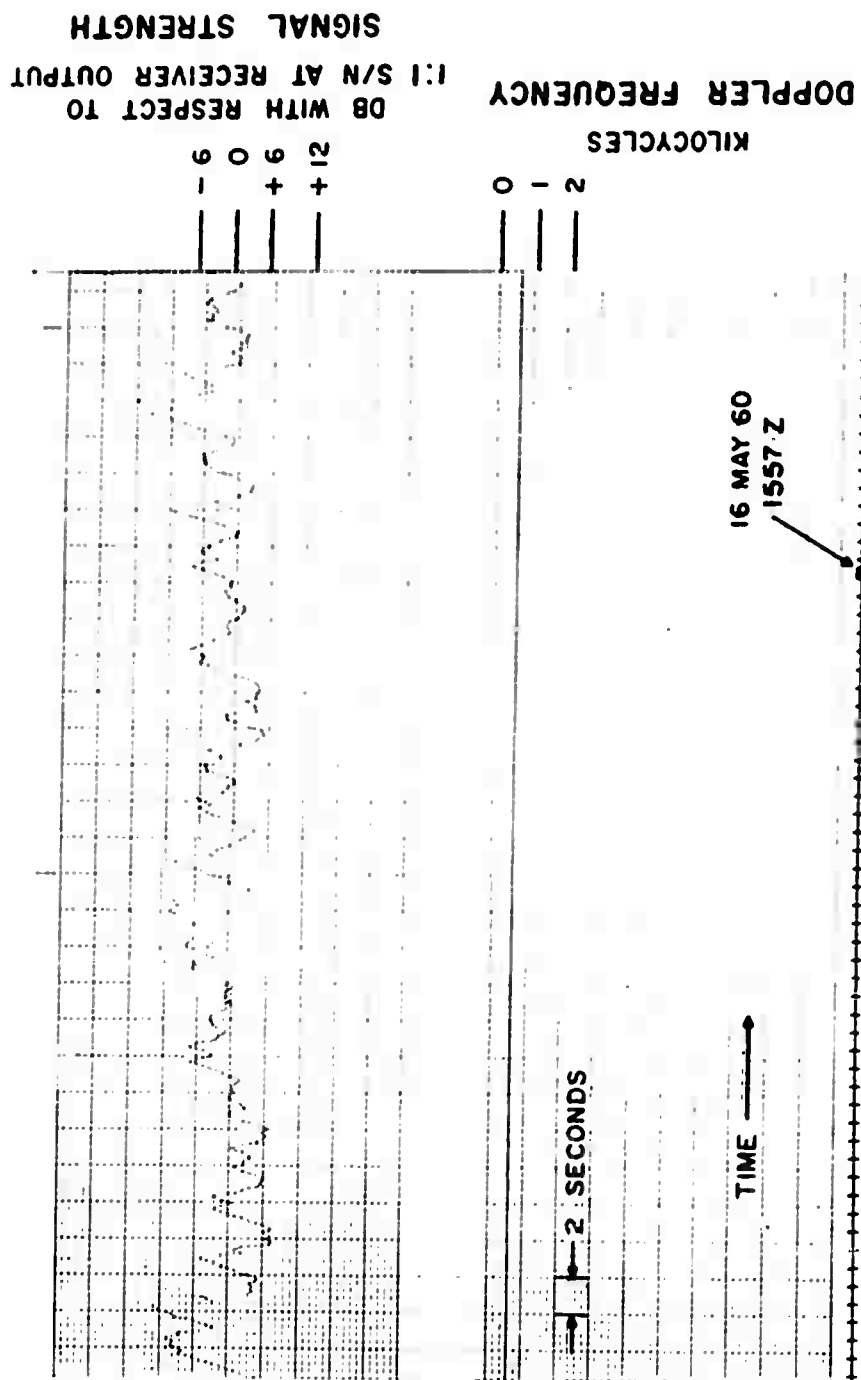
DOPPLER RECORD OF ACTIVE N-S TRACK OF
60 EPSILON I (SPUTNIK IV) REV. 26 AT
ABERDEEN PROVING GROUND, MARYLAND

Fig. 120
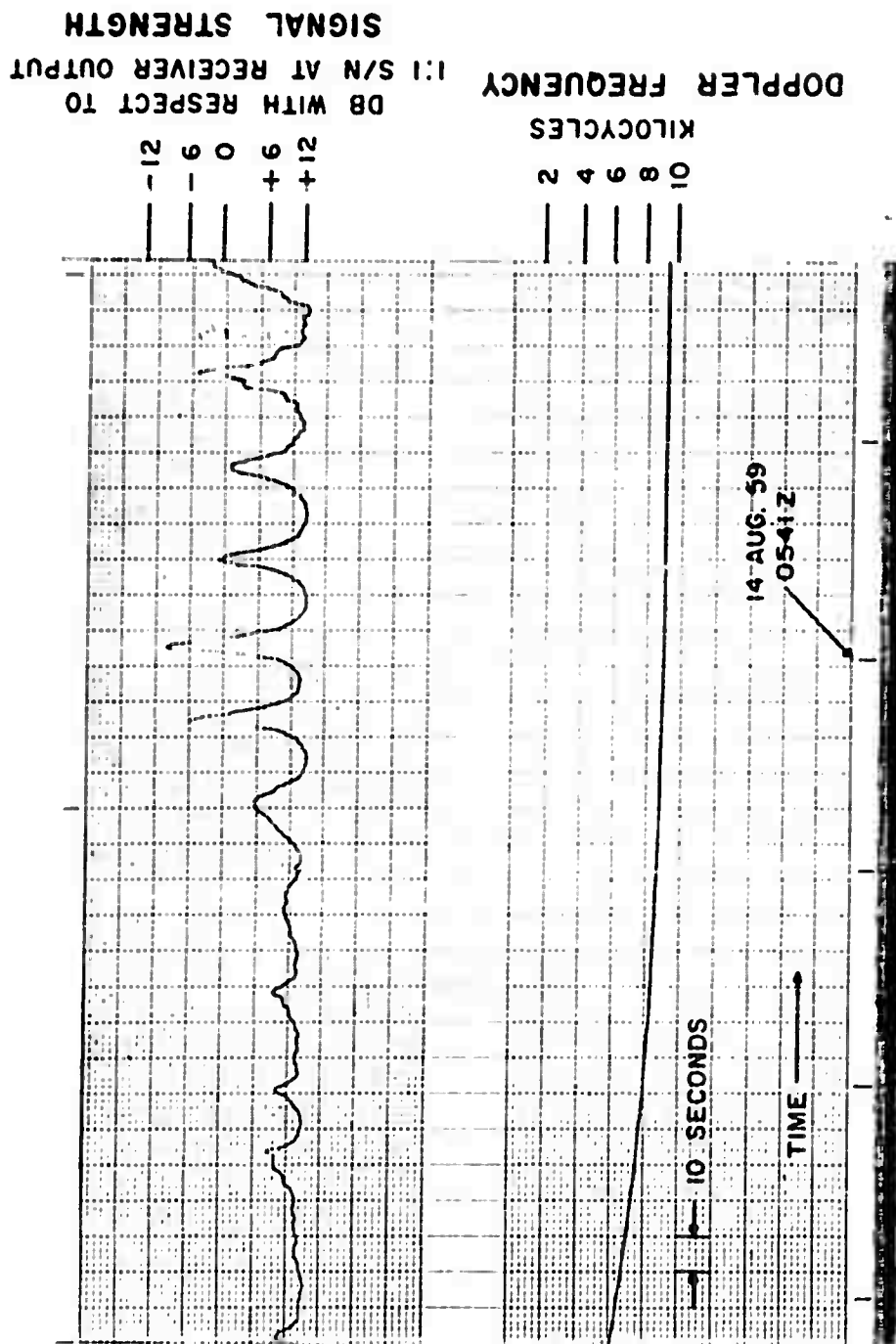
DOPPLER RECORD OF ACTIVE S—N TRACK OF
59 EPSILON (DISCOVERER VI) REV. 7 AT
ABERDEEN PROVING GROUND, MARYLAND
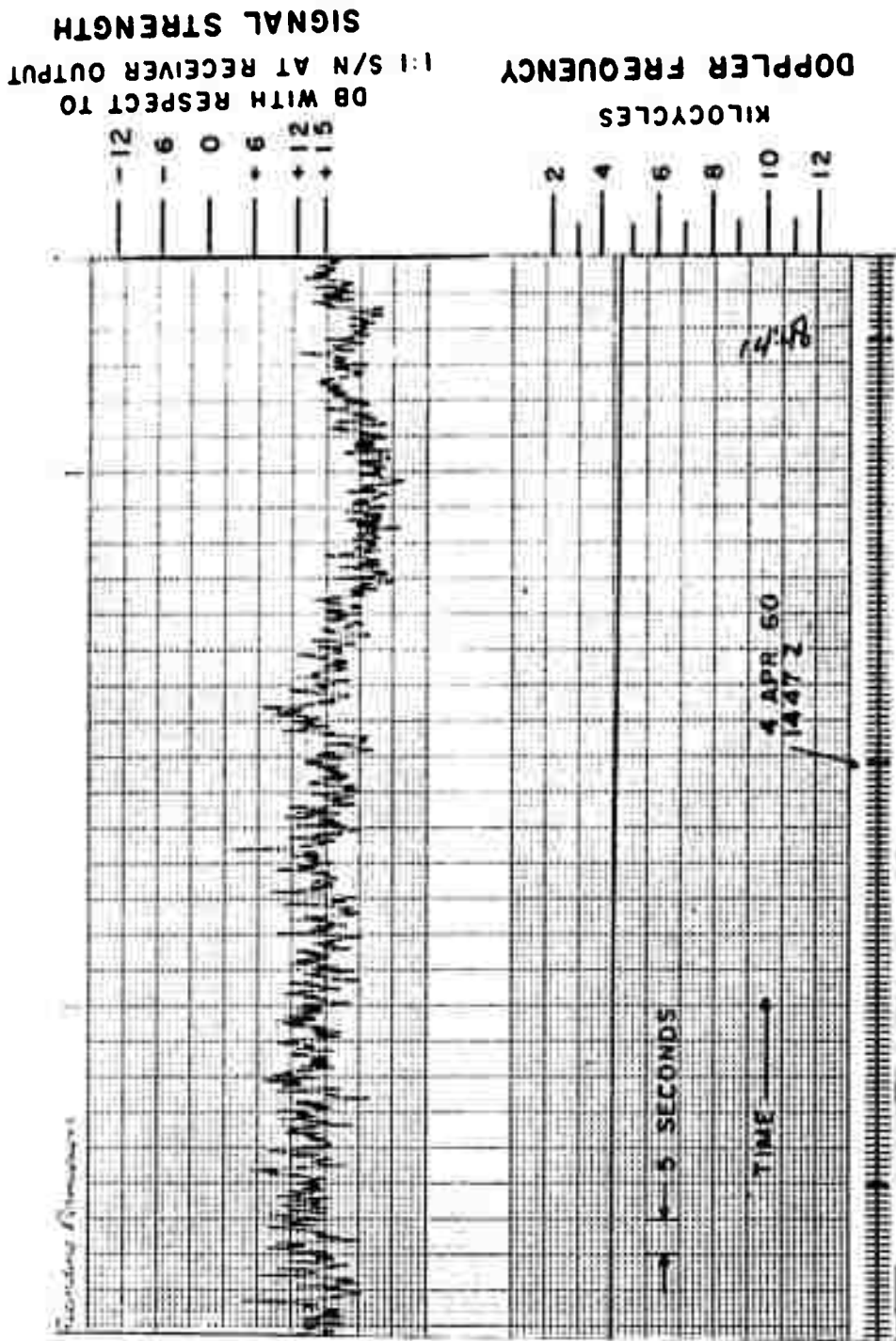
Fig. 121

DOPPLER RECORD OF ACTIVE N-S TRACK OF
58 DELTA (SPUTNIK III) REV. 10007 AT
ABERDEEN PROVING GROUND, MARYLAND

Fig. 122
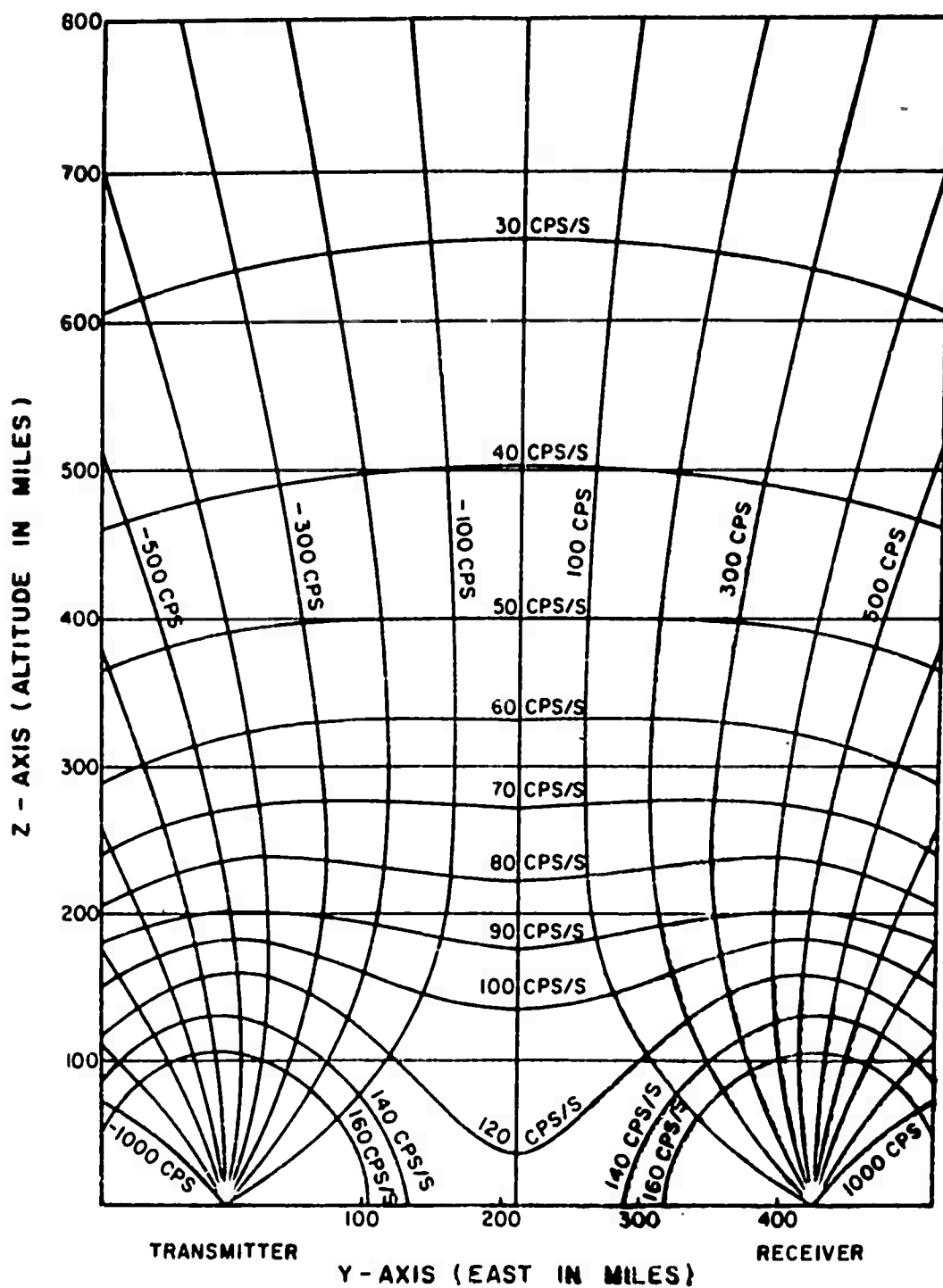
DOPLOC FREQUENCY AND RATE OF CHANGE
OF FREQUENCY AS A FUNCTION OF
POSITION IN THE YZ − PLANE
(FOR 80° INCLINATION)

Fig. 123
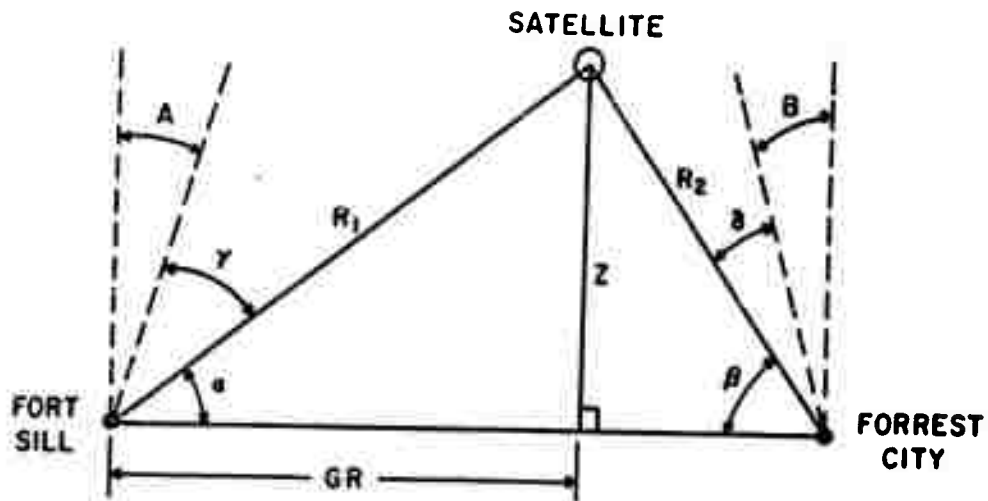
A = 24° = AZIMUTH ANGLE OF TRANSMITTING ANTENNA.

B = 25° = AZIMUTH ANGLE OF RECEIVING ANTENNA.

R_1 = SLANT RANGE FROM TRANSMITTER TO SATELLITE.

R_2 = SLANT RANGE FROM RECEIVER TO SATELLITE.

γ = ANGLE THAT R_1 MAKES WITH CENTER OF TRANSMITTING ANTENNA BEAM.

δ = ANGLE THAT R_2 MAKES WITH CENTER OF RECEIVING ANTENNA BEAM.

α = ANGLE THAT R_1 MAKES WITH BASE LINE.

β = ANGLE THAT R_2 MAKES WITH BASE LINE.

Z = ALTITUDE OF SATELLITE IN CENTER ANTENNA.

GR = GROUND RANGE FROM FORT SILL.

FIG. 124 - CENTER ANTENNA GEOMETRY

180
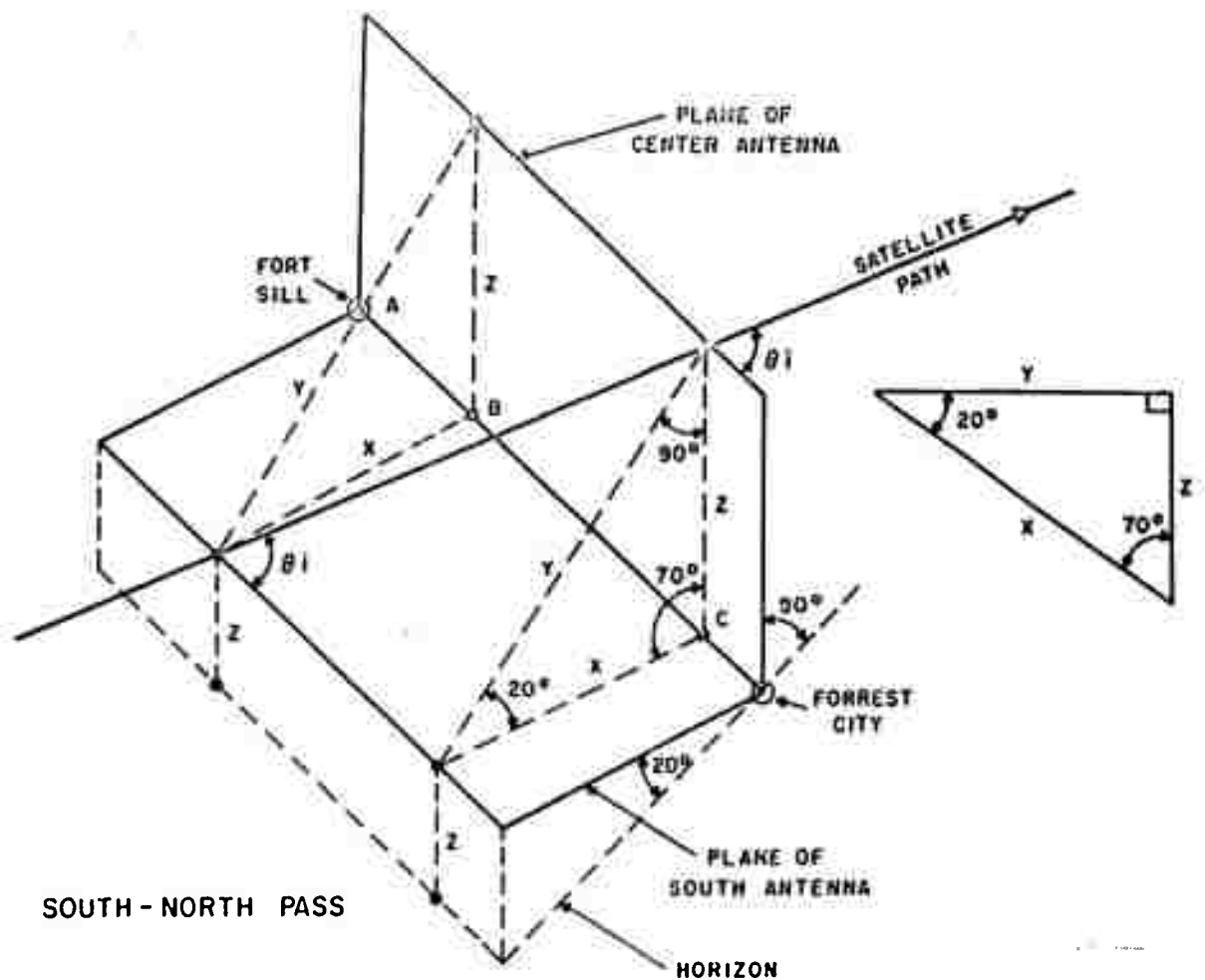
Z = SATELLITE HEIGHT IN CENTER AND NORTH OR SOUTH ANTENNAS.

X = PERPENDICULAR DISTANCE BETWEEN BASE LINE AND SATELLITE INTERSECTION POINT IN NORTH OR SOUTH ANTENNAS.

Y = PERPENDICULAR DISTANCE BETWEEN 20° PLANE AND 90° PLANE.

AC = r = GROUND RANGE IN CENTER ANTENNA.

BC = d = DISTANCE MOVED ALONG BASE LINE.

AB = GROUND RANGE IN SOUTH .ANTENNA.

θi = ANGLE BETWEEN SUB - SATELLITE TRACE AND BASE LINE.

FIG. 125 - ALTITUDE AND GROUND RANGE

GEOMETRY IN SOUTH ANTENNA

SATELLITE
PATH

FORREST CITY

θi

$\theta i = (i' - 3°)$

3°   i'

N. LATITUDE ϕ

FORT
SILL

3°

i

EQUATOR

SOUTH - NORTH PASS

FORREST
CITY

θi

$\theta i = (i' + 3°)$

3°   i'

N. LATITUDE ϕ

FORT
SILL

3°

i

EQUATOR

NORTH - SOUTH PASS
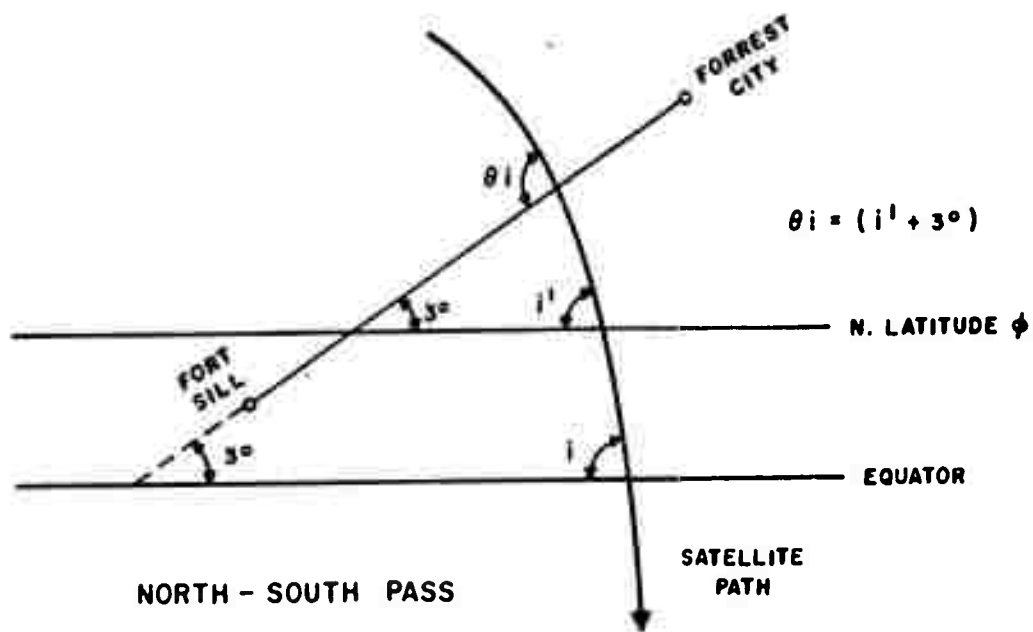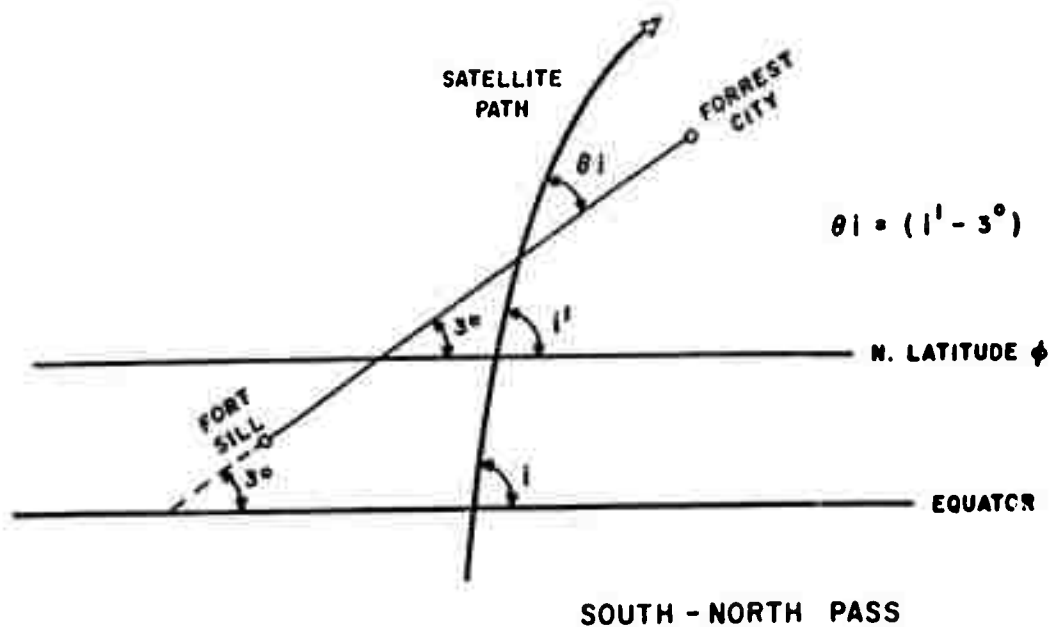
SATELLITE
PATH

i = ORBITAL INCLINATION AT EQUATOR.

i' = ORBITAL INCLINATION AT NORTH LATITUDE ϕ.

θi = ANGLE BETWEEN SUB-SATELLITE TRACE AND BASE LINE.

FIG. 126 - SATELLITE INCLINATION WITH

RESPECT TO BASE LINE
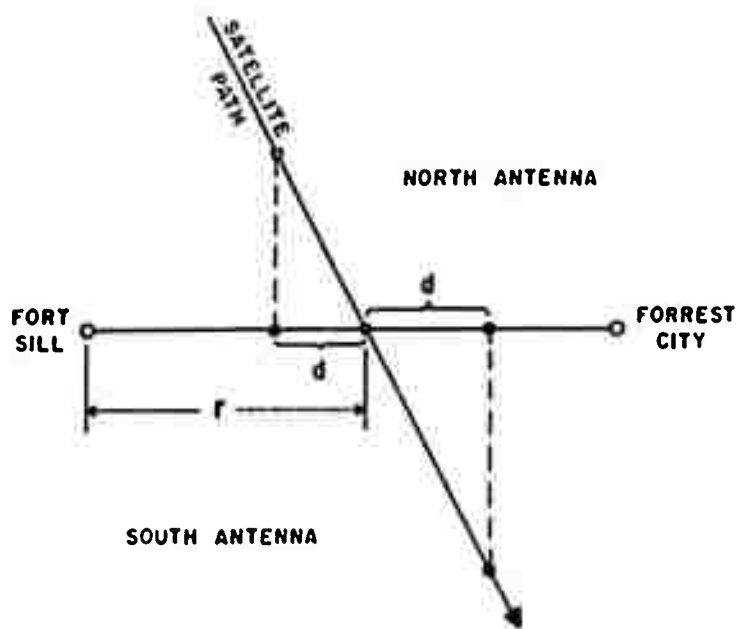
182

NORTH ANTENNA

FORT
SILL

FORREST
CITY

d

d

r

SOUTH ANTENNA

NORTH - SOUTH PASS

GROUND RANGE (GR)

IN NORTH ANTENNA = $r - d$

IN SOUTH ANTENNA = $r + d$

WHERE r = GR IN CENTER
ANTENNA AND IS EAST OF
FORT SILL, AND D = DISTANCE
MOVED ALONG BASE LINE.

NORTH ANTENNA

FORT
SILL

FORREST
CITY

r

d

d
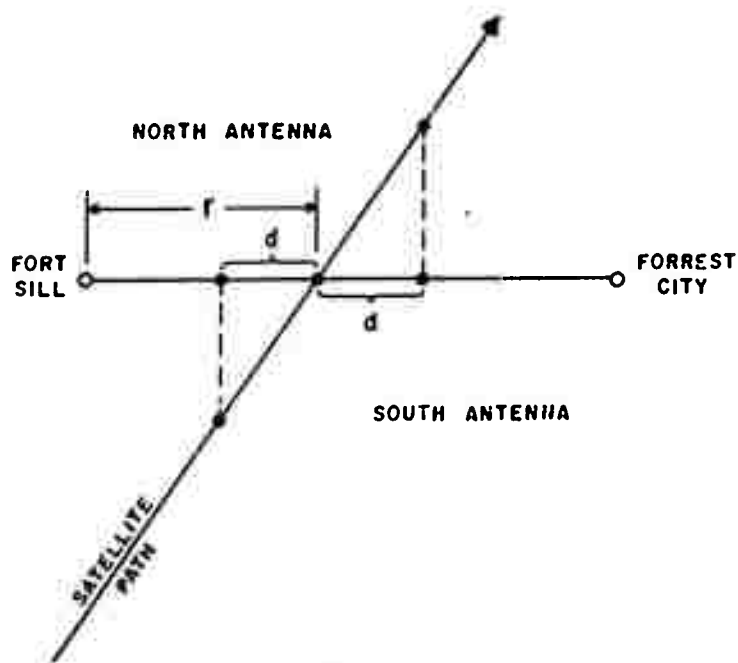
SOUTH ANTENNA

SOUTH - NORTH PASS

GROUND RANGE (GR)

IN NORTH ANTENNA = $r + d$

IN SOUTH ANTENNA = $r - d$

WHERE r = GR IN CENTER
ANTENNA AND IS EAST OF
FORT SILL, AND D = DISTANCE
MOVED ALONG BASE LINE.

FIG. 127 - GROUND RANGE IN NORTH AND SOUTH ANTENNAS
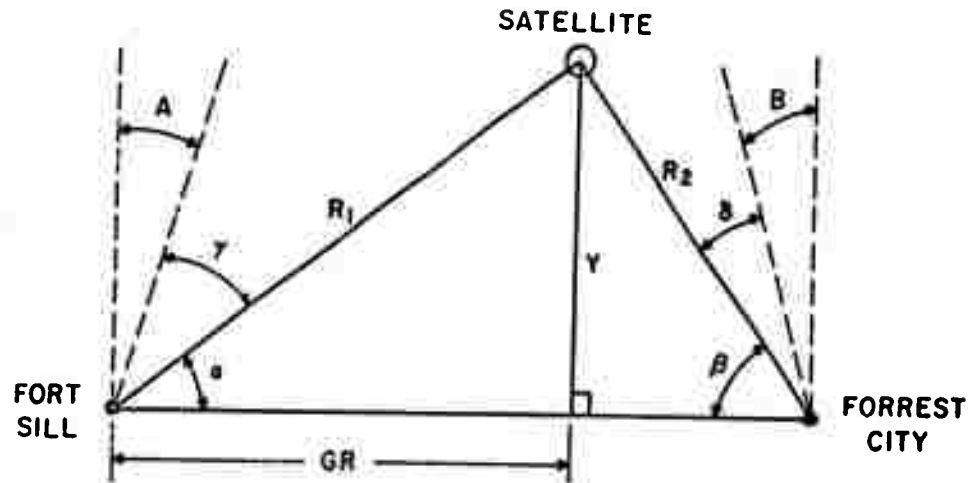
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B = 25° = AZIMUTH ANGLE OF RECEIVING ANTENNA.

R_1 = SLANT RANGE FROM TRANSMITTER TO SATELLITE.

R_2 = SLANT RANGE FROM RECEIVER TO SATELLITE.

γ = ANGLE THAT R_1 MAKES WITH CENTER OF TRANSMITTING ANTENNA BEAM.

δ = ANGLE THAT R_2 MAKES WITH CENTER OF RECEIVING ANTENNA BEAM.

α = ANGLE THAT R_1 MAKES WITH BASE LINE.

β = ANGLE THAT R_2 MAKES WITH BASE LINE.

Y = PERPENDICULAR DISTANCE BETWEEN SATELLITE INTERSECTION POINT IN 20° PLANE AND 90° PLANE.

GR = GROUND RANGE FROM FORT SILL.

FIG. 128 - NORTH AND SOUTH ANTENNA GEOMETRY

POWER FACTOR VS. ANGULAR POSITION
FOR AN 0 X 76° ANTENNA

FIG. 129
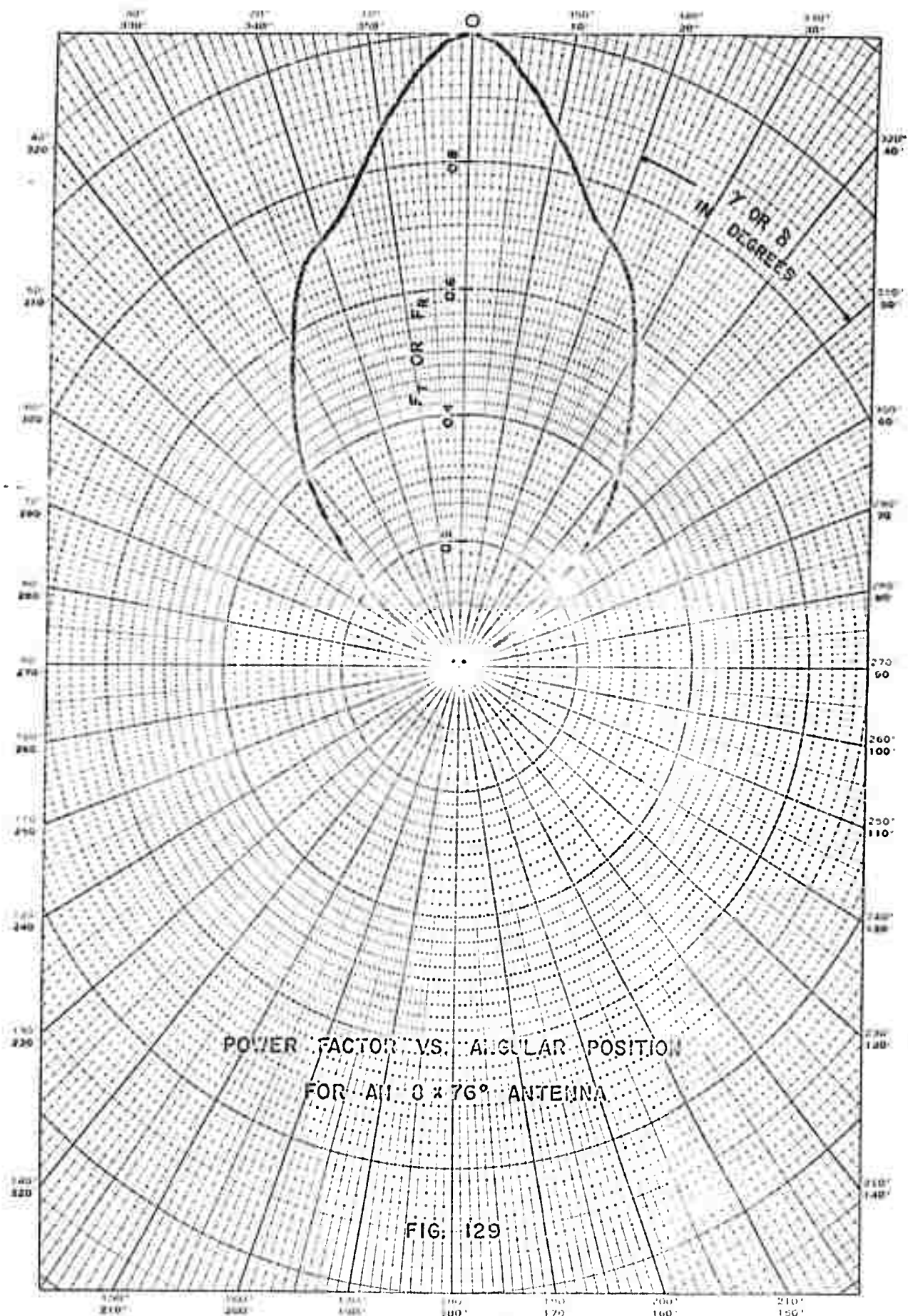
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187

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Ballistic Research Laboratories, APG
DOPLOC OBSERVATIONS OF REFLECTION CROSS
SECTIONS OF SATELLITES
Harold T. Lootens

Satellites - Detection
Radar tracking - Satellites
Doppler tracking systems -
Design

BRL Memorandum Report No. 1330 March 1961

DA Proj No. 503-06-011, OMSC No. 5210.11.143

This report presents reflection cross sections observed for eight
satellites during the period 1 January 1959 to 1 July 1960, using the DOPLOC
"dark satellite" detection system developed by the Ballistic Research Labora-
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